

Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites : Indigenous Microfossils, Minerals, or Modern Bio-Contaminants?



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Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites

Detection of Valid Microfossils in Meteorites is Directly
Relevant to Fundamental Question of Astrobiology:
Is Life restricted to Earth or does Life exist elsewhere in the Cosmos?

Validity Criteria:

Biogenicity: *Are the putative microfossils unambiguously Biological?*
Must be large enough to be autonomous organisms with sufficient chemical and morphological complexity and differentiation to distinguish them from abiotic mineral crystals and coating artifacts

Indigeneity: *Are the putative microfossils undeniably Indigenous?*
Must be established that the possible microfossils are Indigenous and not Mineral Artifacts or Modern Bio-Contaminants



Instrumentation for Meteorite Study at NASA/MSFC - 1996-2011

ElectroScan Environmental Scanning Electron Microscope (ESEM)

Water vapor (10 Torr vacuum) 90-100,000X; SED; Noran EDS (Z> Boron)

Hitachi S-4100 Field Emission SEM (FESEM)

Cold cathode field emission electron gun; 20 - 300,000X;

Secondary Electron (SED) & Backscattered Electron Detector (BSED); KEVEX
EDS - Lithium Drifted Silicon detector (Z>Boron)

Hitachi S-3700N Variable Pressure Scanning Electron Microscope

Tungsten emitter electron gun; 5 - 300,000X; SED & BSED;

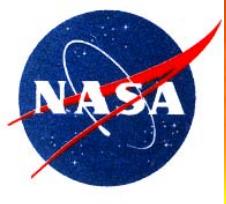
4 Pi EDS - Silicon Drifted Silicon Detector (Z>Boron)

FEI Quanta 600 (FESEM and ESEM)

Simultaneous SED and BSED images;

4 Pi EDS - Lithium Drifted Silicon detector (Z>Boron)

Olympus, Zeiss & Leitz Optical and Epifluorescence Microscopes



Filamentous Thiomicro Prokaryotes in Carbonaceous Meteorites **CONTAMINATION CONTROL**



Study Confined to Freshly Fractured Interior Surfaces

Optical Microscopy to Observe Surface Cracks

Meteorite Fusion Crust and Old Cracks Avoided

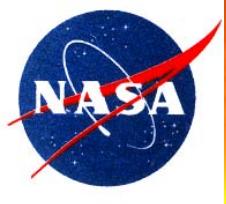
New Mount Stubs & Sterile Tools Used

Flame Sterilization of containers stubs & Tools

Long term storage in sealed vials @-80C or dessicator

Uncoated samples used - No contact with liquids

Sample into ESEM or FESEM chamber right after fracturing



Meteorites Investigated at NASA/MSFC



Carbonaceous Chondrites

CI1: Alais, Ivuna & Orgueil

C2 Ungrouped: Tagish Lake

CM2: Murchison, Mighei, Murray & Nogoya

CR: Acfer 324; CK4: Karoonda;

CO3: Rainbow, Dar al Gani 749 & Kainsaz

CV3: *Allende* & Efremovka

Stony Chondrites, Achondrites & Iron Meteorites

L4: Nikolskoye & Barratta; L/LL6: Holbrook;

Diogenite: *Tatahouhine*; Iron: *Henbury*; 20 Thiel Mt.

Italics: Remains of Microfossils Never Detected



Flamentous Thiomicro Prokaryotes in Carbonaceous Meteorites

Murchison CM2 Meteorite



Fall: 10:59 A.M.
9/18/1969 - Murchison,
Australia
>100 kg. recovered –
Chondrules Present
Magnetites U/Pb Age ~ 4.56 Gya
Cosmic Ray Exposure ~ 800 Kya





Murchison CM2 Meteorite

- CM2 Carbonaceous Chondrite with Chondrules
- Extensive Alteration by Water on Parent Body

Hydrous Phyllosilicates – Clay Minerals - Serpentines

*Chemically Primitive - Except for Volatiles the
Elemental Abundances ~ Solar Photosphere*

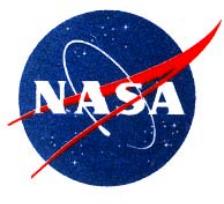
~2.5 wt. % Carbon; ~ 3-11% Extraterrestrial Water,

- Insoluble Organic Matter~Lignite Coal-Kerogen

- 74 Amino Acids - (α -Aib, Gly, β -Ala & IVal) - Abundant
Missing Amino Acids

(Phe, Tyr, Lys, His, Arg & Trp) -- Never Detected in
Murchison or Orgueil

Inconsistent with Modern Bio-Contaminants



Murchison CM2 Meteorite

SAMPLES INVESTIGATED

1 stone: (4.2 gm) E12391: *Sand Pits near Produce Stand*

Tr. Univ. Melbourne 3564 - *Nature Phys. Sci.* 230, 18-20

Courtesy: Dr. William Birch

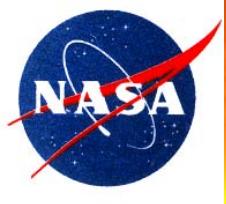
1 stone (3.5 gm) E4806: *Near Murchison East*

Prof. J. Lovering 10-2-1971

1 stone (2.5 gm) E12314: *Near Abbington Farm, Murchison*

Courtesy: Dr. William Birch

*Victoria Museum,
Melbourne, Australia*

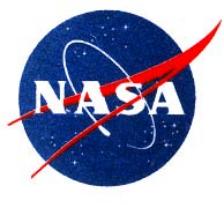


Orgueil CI1 Meteorite

Fall: May 14, 1864



Over 20 black stones 18 km EW Scatter Ellipse ($43^{\circ} 54' N$; $01^{\circ} 24' E$)
Villages of Orgueil (Tarn-et-Garonne), Campsas & Nohic, France



Orgueil CI1 Meteorite

- CI1 Carbonaceous Chondrite - No Chondrules
- Micro-regolith Breccia (Particulates 1 nm–100 μ)
- Extensive Aqueous Alteration on Parent Body
Silicate Minerals converted to Hydrous Phyllosilicates
Clay Minerals - Serpentines
- Primitive Chemistry – *Except for Volatiles the Elemental Abundances of Orgueil ~ Solar Photosphere*
- ~3.5 wt% C; ~ 17-22% Extraterrestrial Water,
62.5% Chlorite - $(\text{Fe}, \text{Mg}, \text{Al})_6(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_8$
- 6.7% Epsomite $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ & Ammonium Salts
- Insoluble Organic Matter ~ Bitumen or Kerogen



Orgueil CI1 Meteorite

SAMPLES INVESTIGATED

Musée Nationale d'Histoire Naturelle, Paris

1 stone: MNHP #S219: (0.5 gm). *Courtesy: Dr. Claude Perron*

2 stones: (0.6 gm & 0.3 gm). *Courtesy: Dr. Martine Rossignol-Strick*

1 stone: Monbequi MNHP#225: (0.305 gm). *Dr. Brigitte Zanda*

1 stone - Campsas MNHP#246 (0.03 gm). *Dr. Brigitte Zanda*

*DuPont Meteorite Collection
Planetary Studies Foundation, Chicago*

2 stones: (0.4 gm & 0.1 gm). *Courtesy: Dr. Paul Sipiera*



Filamentous Trichome

Prokaryotes in Carbonaceous

Meteorites

TRICHOMIC CYANOBACTERIA



Oxygenic Photosynthetic Prokaryotes

Photoautotrophs-Use H₂O as Photoreductant & CO₂ as Source of C for Energy & release Oxygen
Some are Facultative Chemoheterotrophs and use

PSII for *Anoxygenic Photosynthesis of H₂S*

Reproduce by Fragmentation & Hormogonia;
Binary Fission, Multiple Fission, Spores/Akinetes

Precise Size & Characteristics of Cells, Sheath,
Trichome & Filament Taxonomic Diagnostic



Flamentous Thienomic Prokaryotes in Carbonaceous Meteorites

MODERN CYANOBACTERIA Samples Investigated



Plectonema (Lyngbya) wollei–Lake Guntersville, Alabama
Hoover Collected, May, 2004 (Growing Environmental Sample)

Lyngbya (Leptolyngbya) subtilis – *Lake Michigan*, A. St. Amand,
Phycotech, Inc. (Fixed Environ. Sample)

Oscillatoria lud – *UTex Coll. LB 1953 (Axenic Culture at NSSTC)*

Arthrosphaera platensis– *Carolina Biological Axenic Culture at NSSTC*

Tolypothrix distort–*Carolina Biolical Axenic Culture at NSSTC*

Calothrix membranaceae–*Carolina Biolical Axenic Culture NSSTC*

Cylindrospermum sp. – *Carolina Biological Axenic Culture NSSTC*

Calothrix sp.–*Little White River, Oregon, A. St. Amand, Phycotech.*
(Fixed Environmental)

Microcoleus chthonoplastes–*L. Gerassimenko, INMI Axenic Culture*



Flamentous Thienomic Prokaryotes in Carbonaceous Meteorites

FOSSIL CYANOBACTERIA Samples Investigated

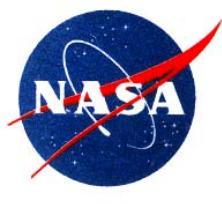


Phosphorite- Lower Cambrian, Khesen fm.,
Tommotian Stage, Khubsugul, Mongolia

Siphonophycus robustum (Schopf) Knoll et al. 1991

Tufa-genic rocks - Upper Archaean (Lopian),
Northern Karelia (2.8 Ga)

*Samples Courtesy: Dr. Alexei Yu. Rozanov,
Paleontological Institute, RAS, Moscow*

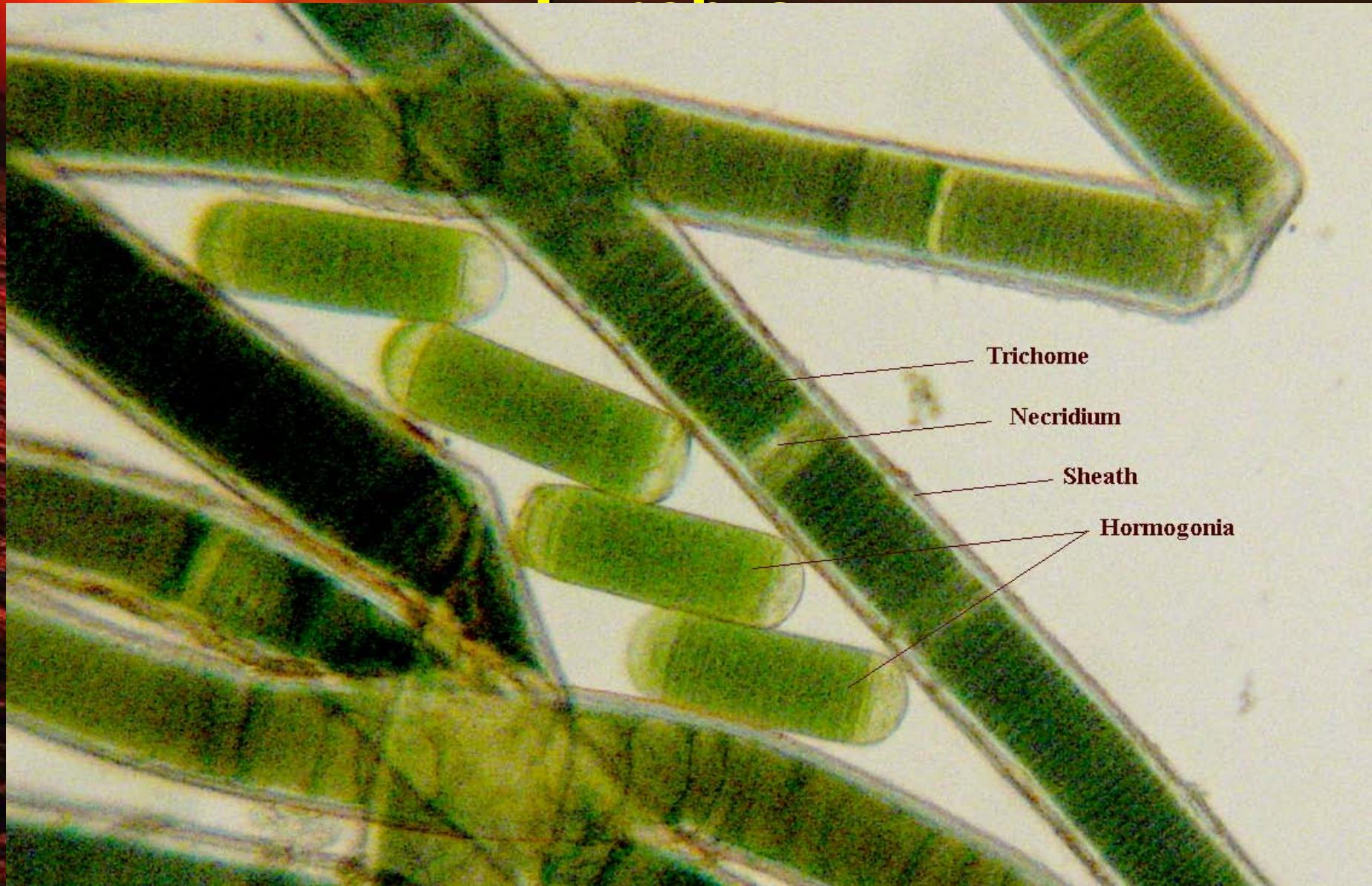


Cyanobacterial Morphology

- ***Trichome***: Linear Chain of Cells - Often in Sheath
- ***Sheath***: Slimy, mucilaginous, colloidal, non-cellular (fine, thick, or lamellated) envelope composed mainly of hydrated polysaccharides
- ***Filament***: Trichome with Polysaccharide Sheath
 - Filament can be Polarized, Uniseriate or Multiseriate, Unbranched; True or False Branching; Constricted; Isodiametric or Tapered*
- Reproduction by Hormogonia or Akinetes
- Nitrogen Fixation by Heterocysts
- Gliding Motility Leaves Twisted Hollow Sheaths



Trichome Cyanobacteria: Filaments and Hormogonia of Lyngbya





Taxonomy of Cyanobacteria

NON-FILAMENTOUS

Order Chroococcales: - Unicellular rods and cocci

(e.g., *Synechococcus*, *Microcystis* *Gloeothece*, *Aphanothece*)

Inconclusive Morphology---Convergence with many other Bacteria,
Archaea, Algae, and Abiotic Forms

PSEUDO-FILAMENTOUS

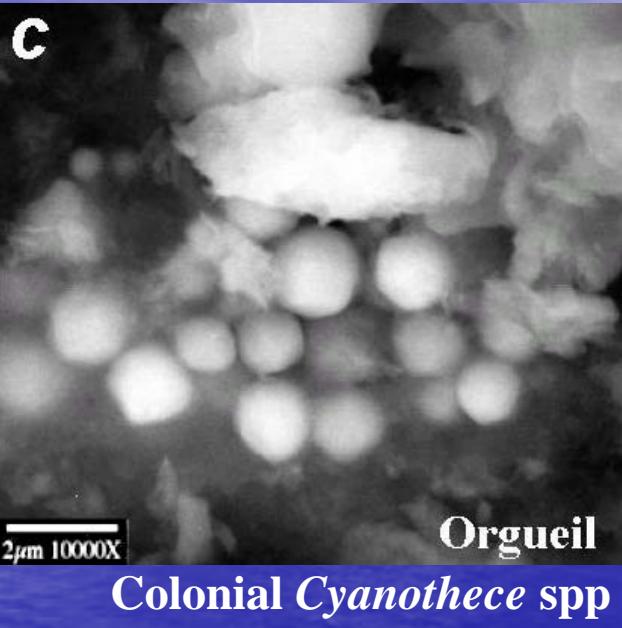
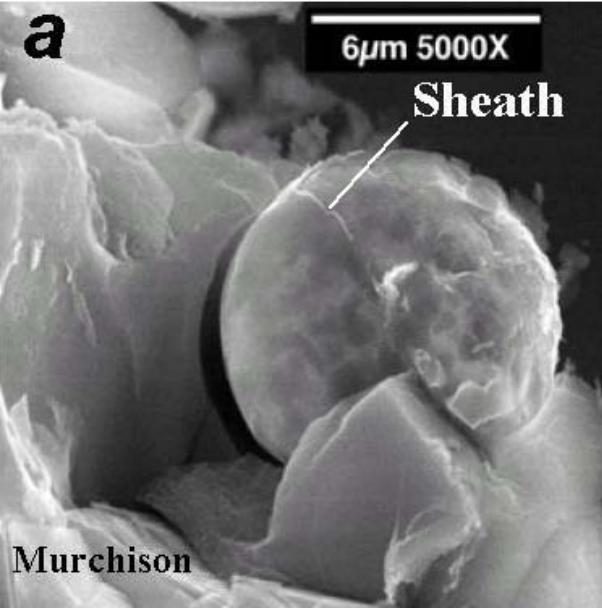
Order Pleurocapsales - Unicellular cyanobacteria

aggregated by shared outer wall layers:

(e.g., *Dermocarpa*, *Chroococcidiopsis*, *Pleurocapsa*)

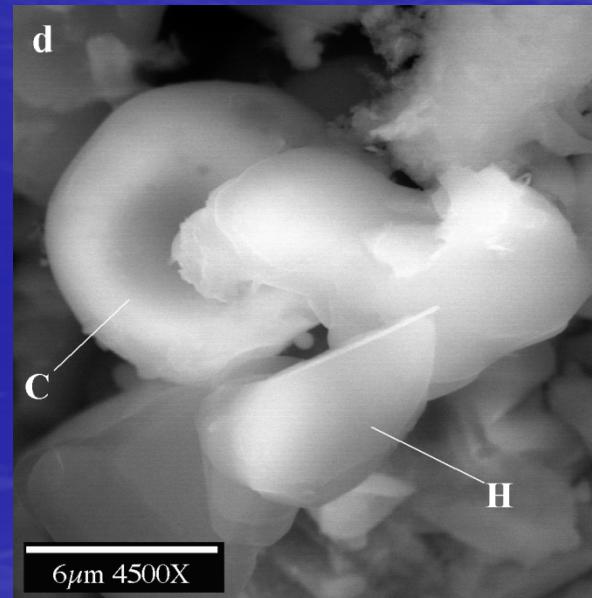
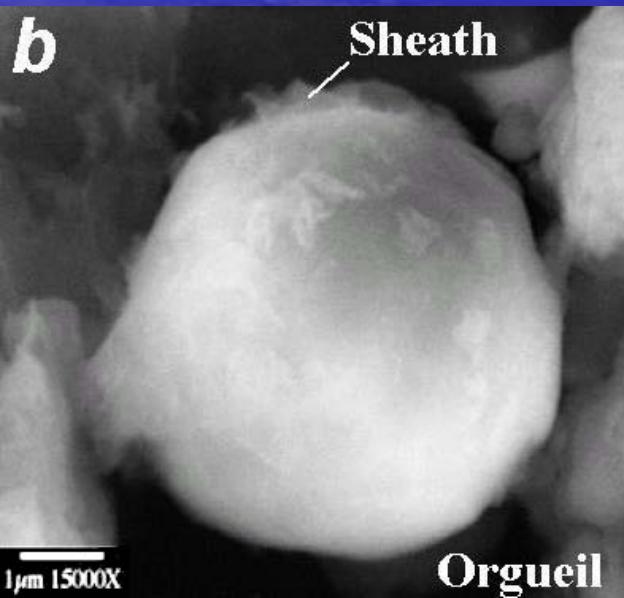


Morphotypes of Order Chroococcales: Cyanobacteria in Murchison & Orgueil



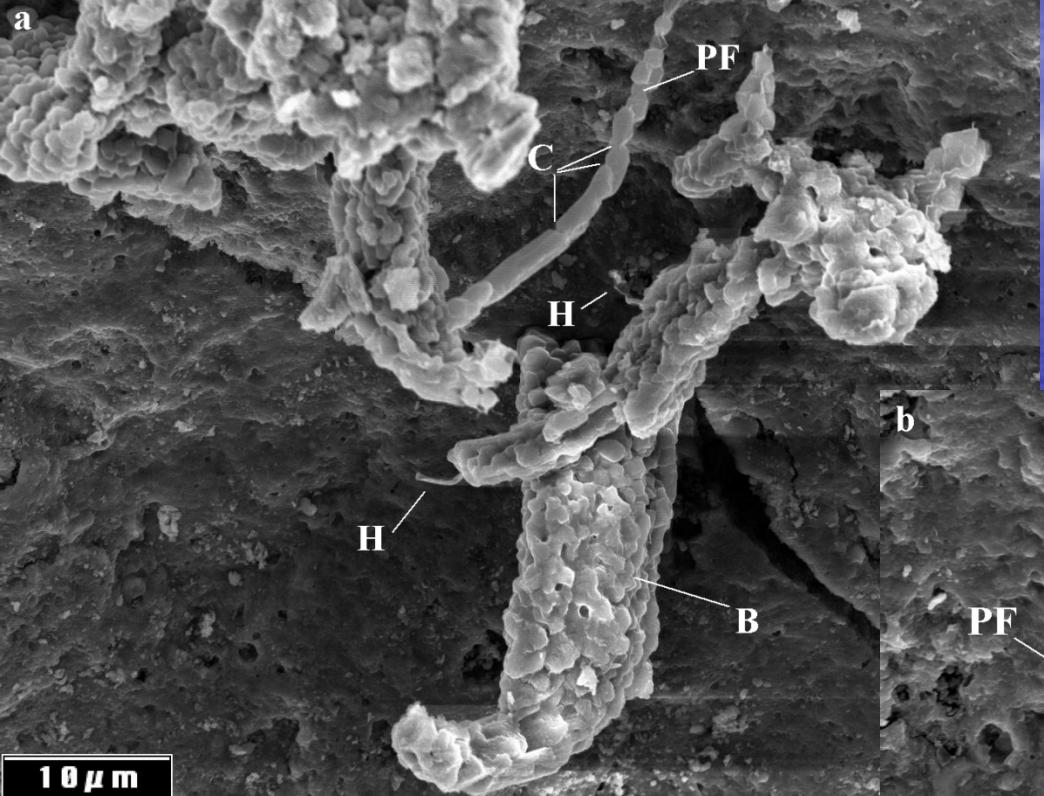
Embedded Coccoidal &
Hemispherical (1-8 μ)
forms in Carbon Envelopes ~
Gleoeocapsa spp.

Common but not Definitive –
Simple Morphologies are not
Unambiguously Biological in
Origin



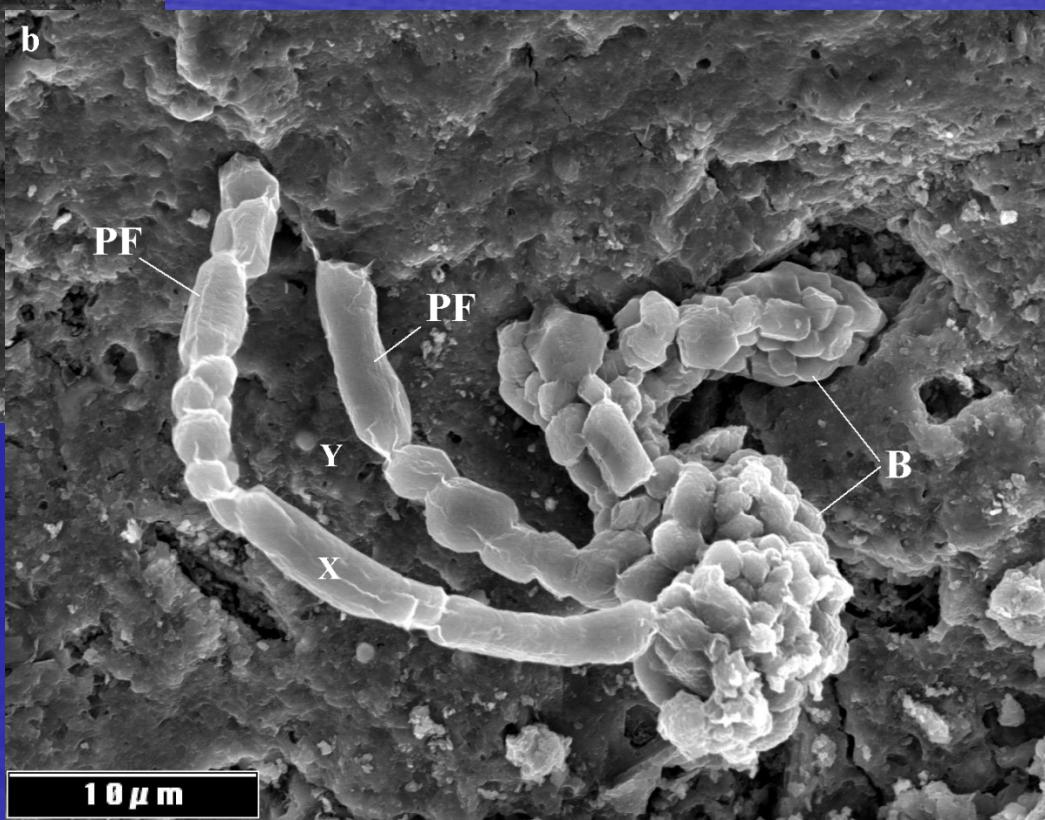


Morphotypes of Order: *Pleurocapsales* Cyanobacteria in Orgueil



Polygonal Coccoids in
Pseudo-filaments with
Terminal Hairs and
Carbonaceous Sheaths
~ Baeocytes

RARE-Found
only in one
Sample of Orgueil





Taxonomy of Cyanobacteria

FILAMENTOUS ORDERS

Order Oscillatoriales: Trichomic Nonheterocystous Isodiametric Uniseriate or Multiseriate Filamentous Cyanobacteria

(e.g., *Oscillatoria*, *Spirulina*, *Lyngbya*, *Microcoleus*, *Phormidium*)
Morphological Convergence with Trichomic Sulfur Bacteria

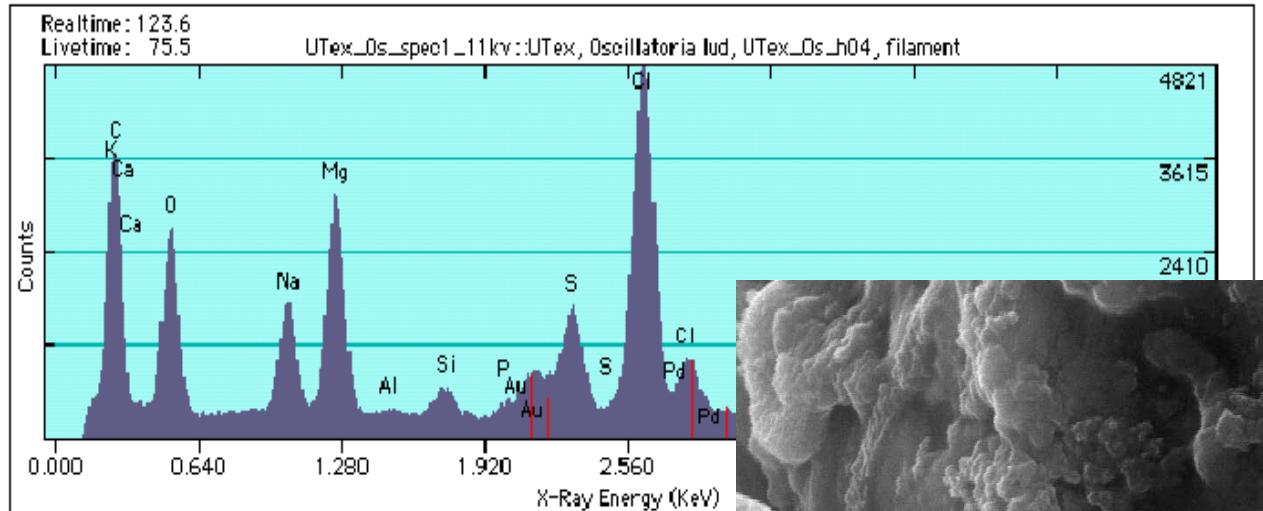
Order Nostocales: Isodiametric Trichomes that form Heterocysts
(e.g., *Anabaenopsis*; *Anabaena*, *Nostoc*; *Cylindrospermum*)

Tapered Trichomes that form Heterocysts at thick end of Trichome.
(e.g., *Calothrix*, *Rivularia*; *Tolypothrix*; *Gloeotrichia*)

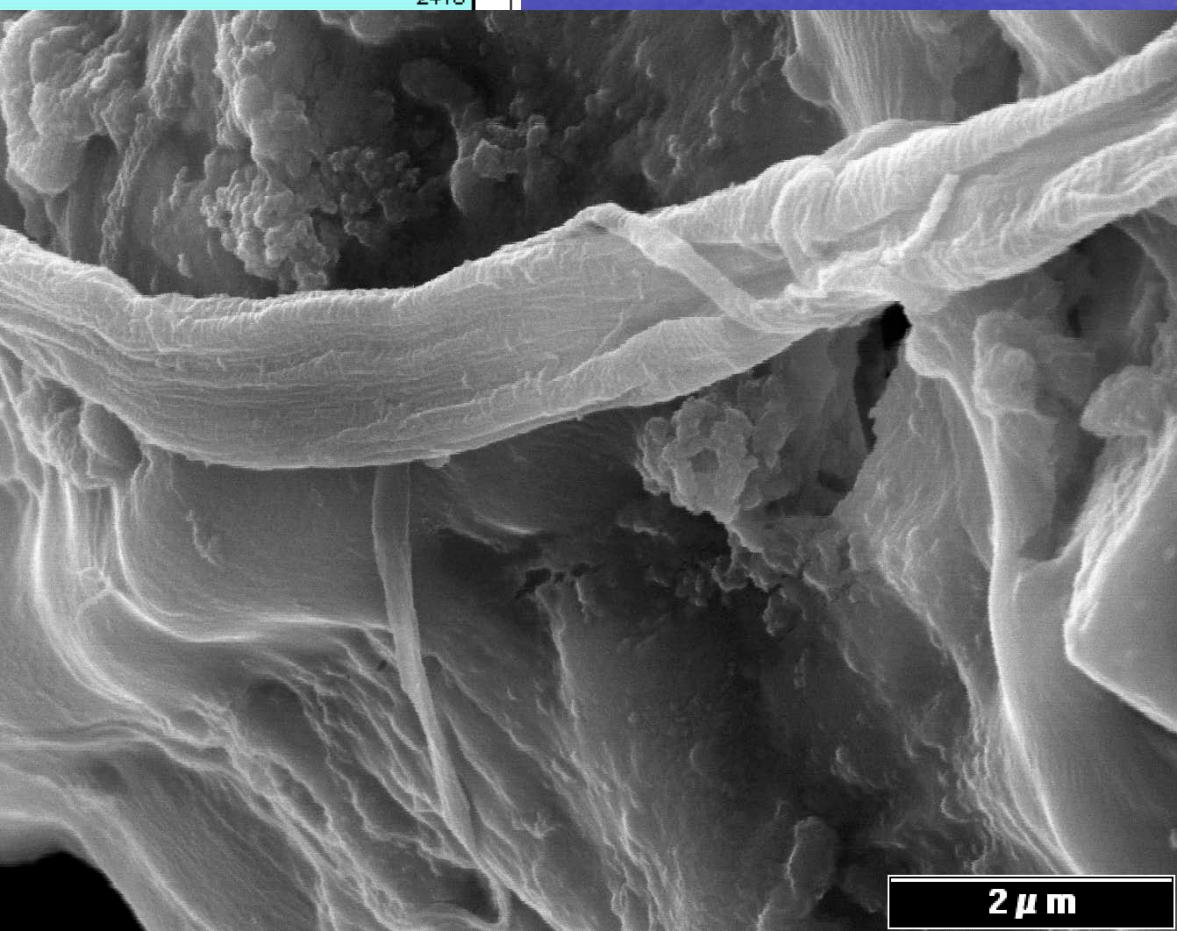
Order Stigonematales: Heterocystous with Branched Trichomes
(e.g., *Stigonema*; *Fischerella*, *Mastigocladopsis* or *Chlorogloeopsis*)
Well-Defined Sizes/Recognizable Morphologies of Polarized Filaments, Trichomes, Sheaths & Specialized Differentiated Cells (Heterocysts, Akinetes, Hormogonia & Branching)



Morphotypes of *Oscillatoriales*: Living UTex *Oscillatoria lud*



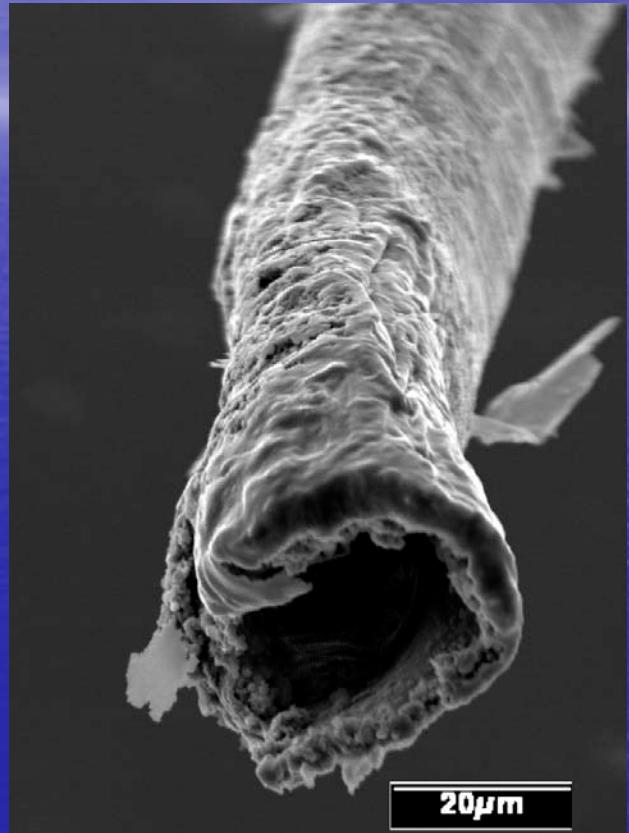
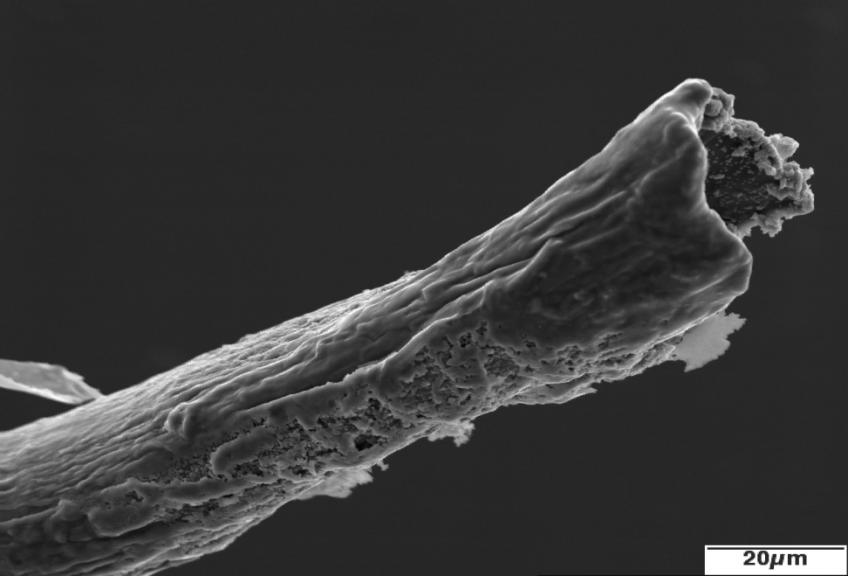
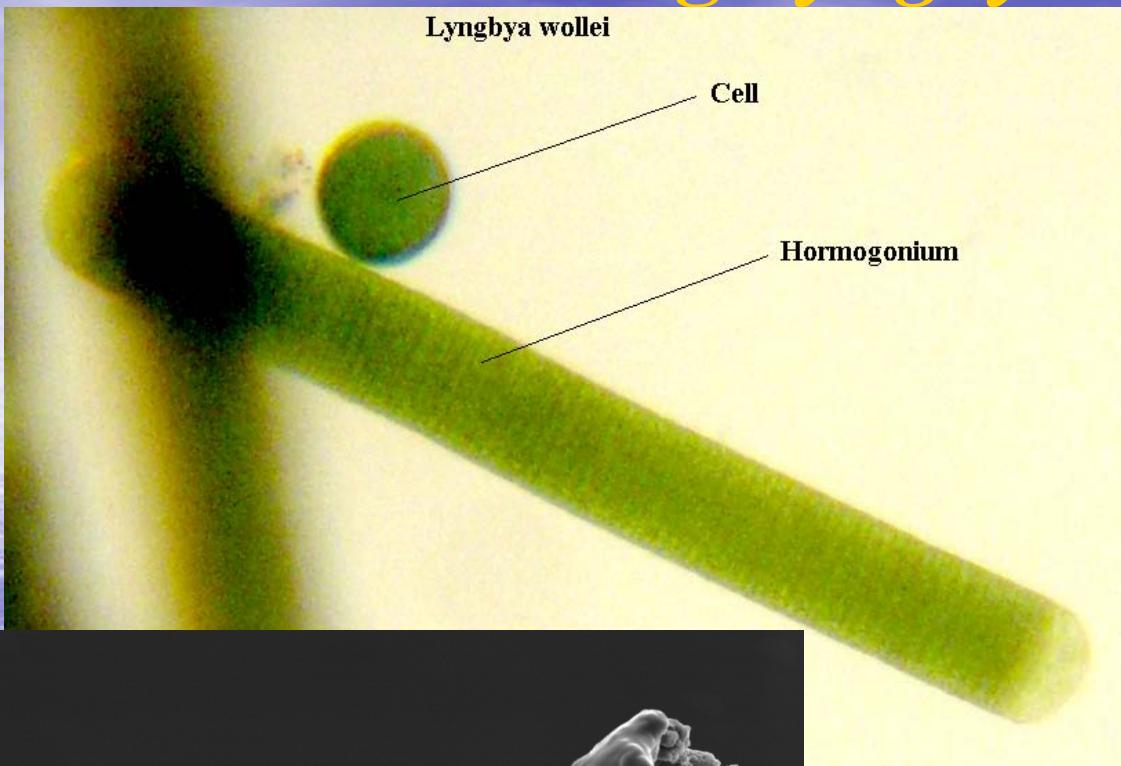
C: 36%
O: 20%
N: 3.4%
S: 4.8%
Cl: 20%
Mg: 8%



2 μ m



Morphotypes of *Oscillatoriales*: Living *Lyngbya wollei*



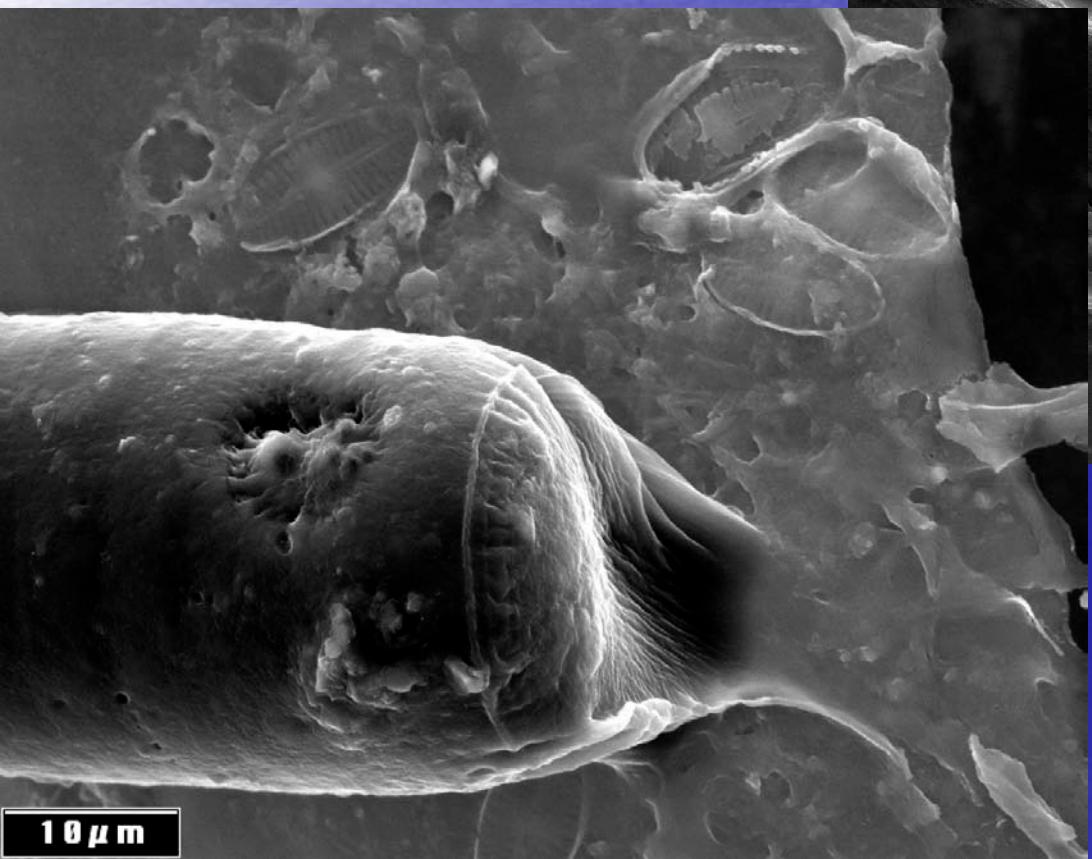
Disk-shaped cells $30\mu\text{ dia.} \times 4\mu\text{ thick}$
O 58%; C 17%; Si 4%; N 3.2%;
S 2%; P .5%; O/C=3.4



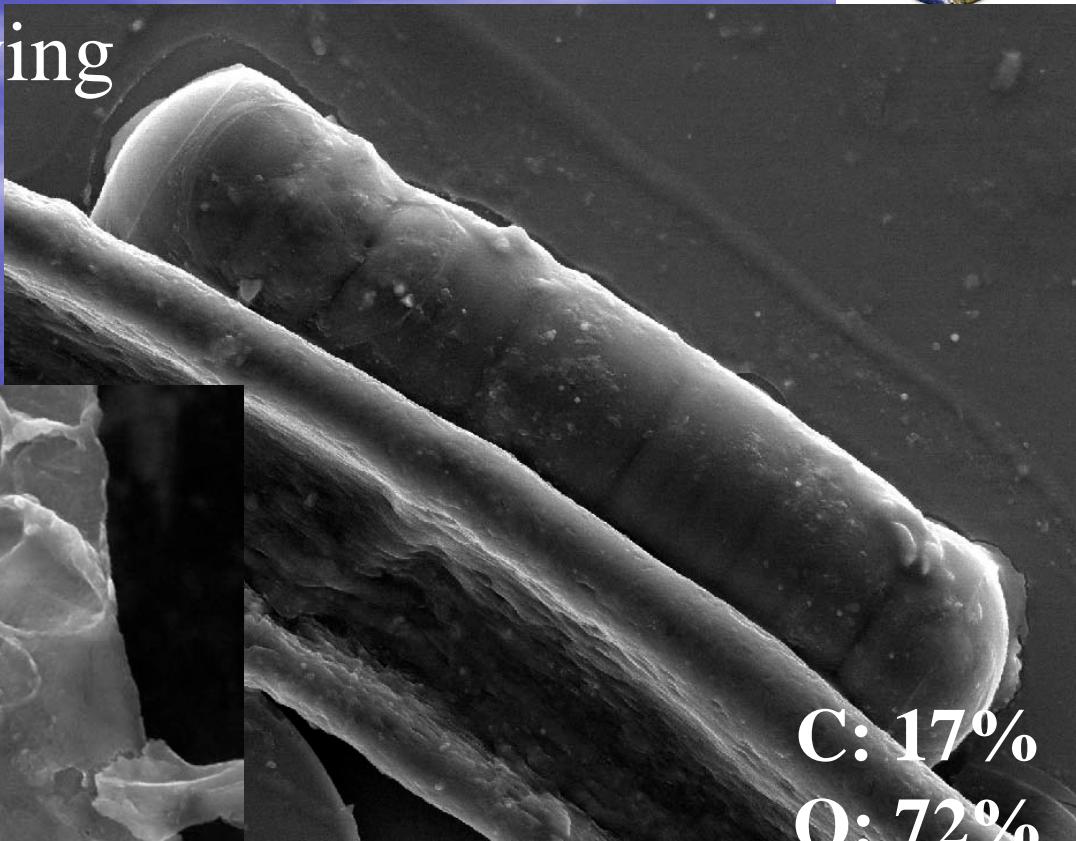
O/C; C/N for Living *Lyngbya wollei* NSSTC



Nitrogen Content of Living
Cyanobacteria
~2-18%



10 μ m

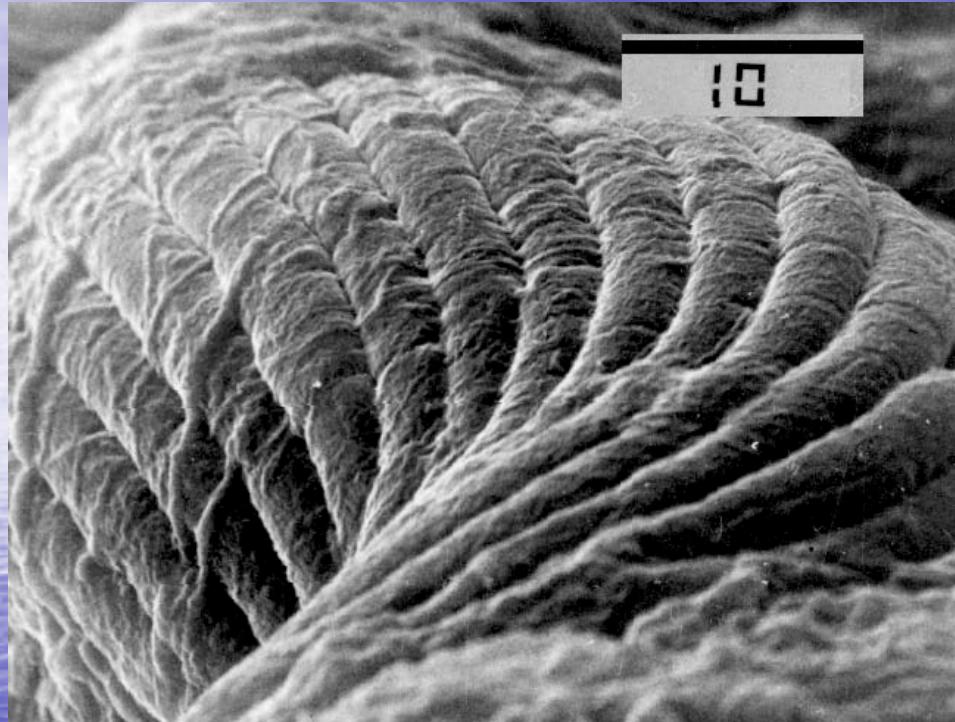


C: 17%
O: 72%
N: 8.2%
P: 0.6%
S: 0.3%
Si: 0.9%

O/C = 4.3
C/N = 2.1

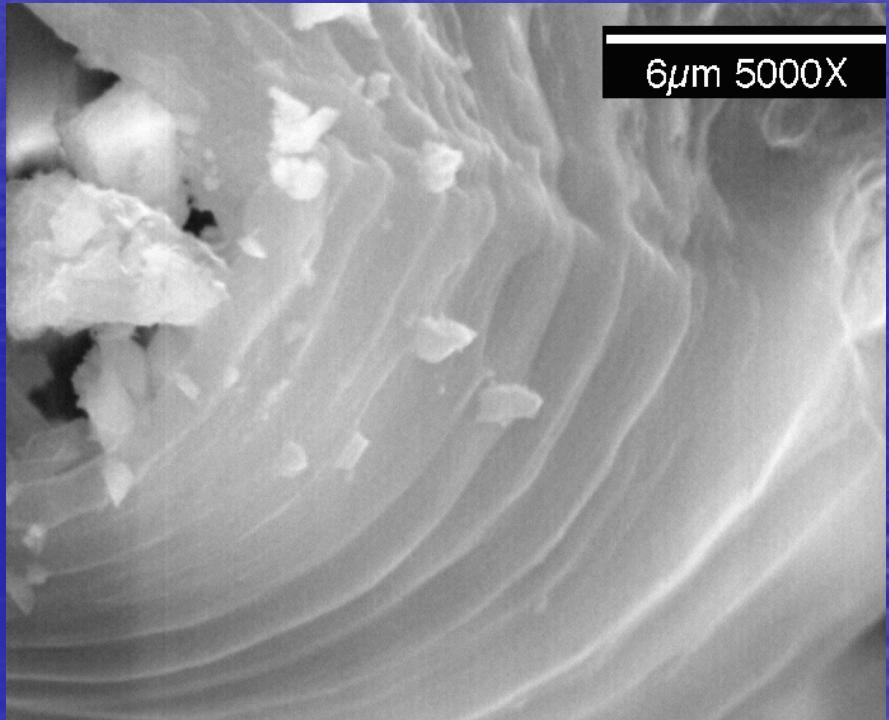


Morphotypes of Order *Oscillatoriales* in Murchison



Living
Microcoleus chthonoplastes
in cyanobacterial mat
Photo : L. Gerasimenko
INMI-RAS

Murchison Multiseriate
Microfossil-Morphotype
of *Microcoleus* sp.

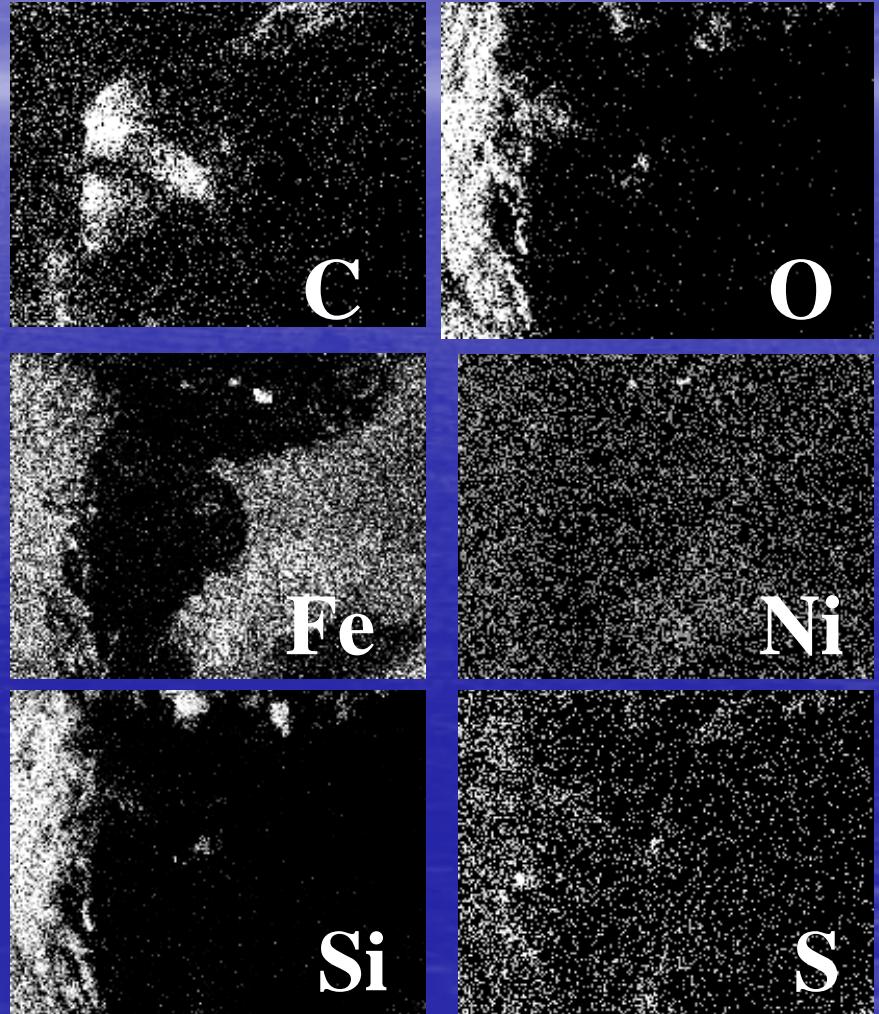
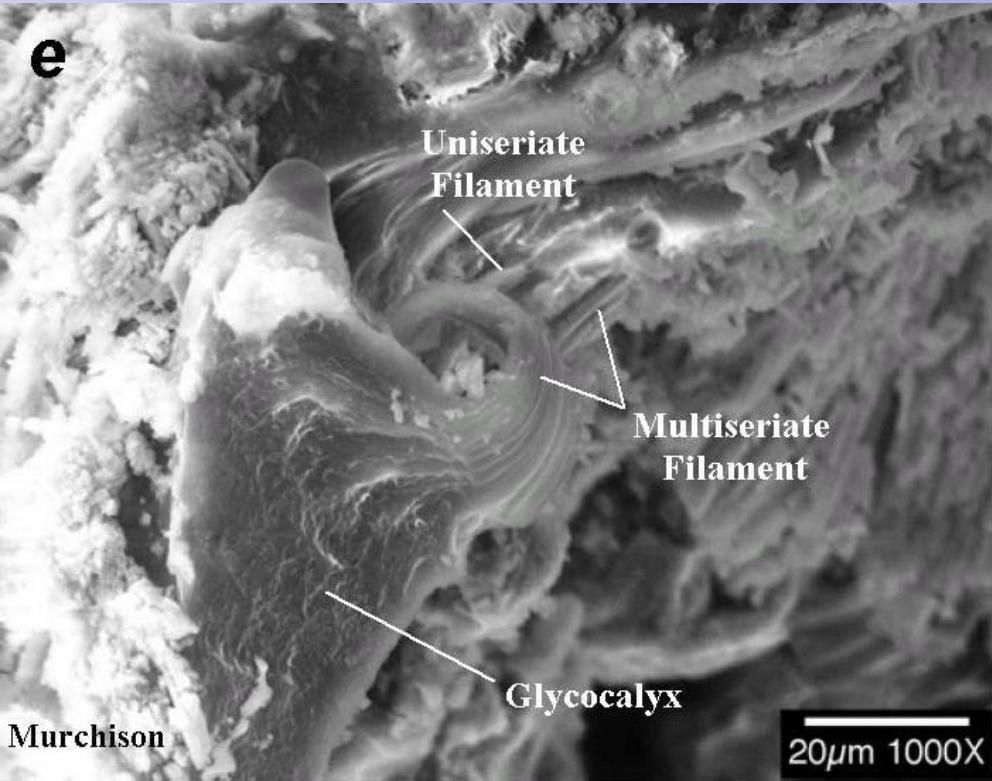




Morphotypes of Order *Oscillatoriales* in Murchison



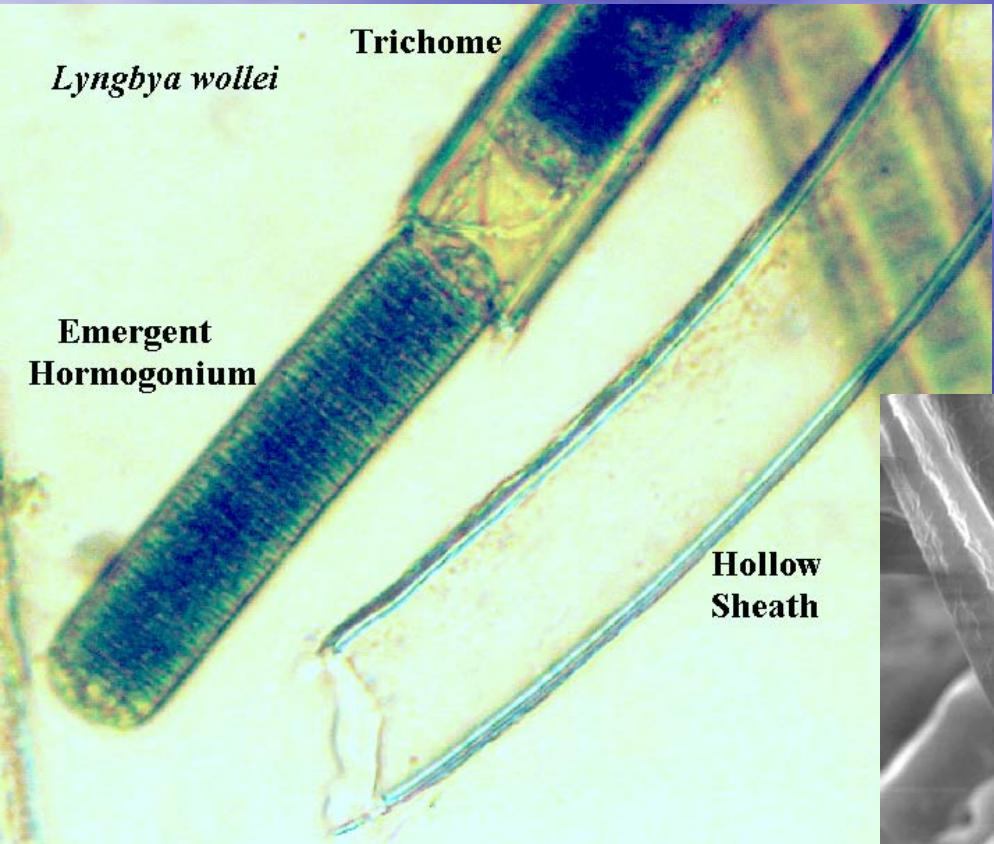
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2D EDS X-Ray Maps of Indigenous Microfossils in Murchison

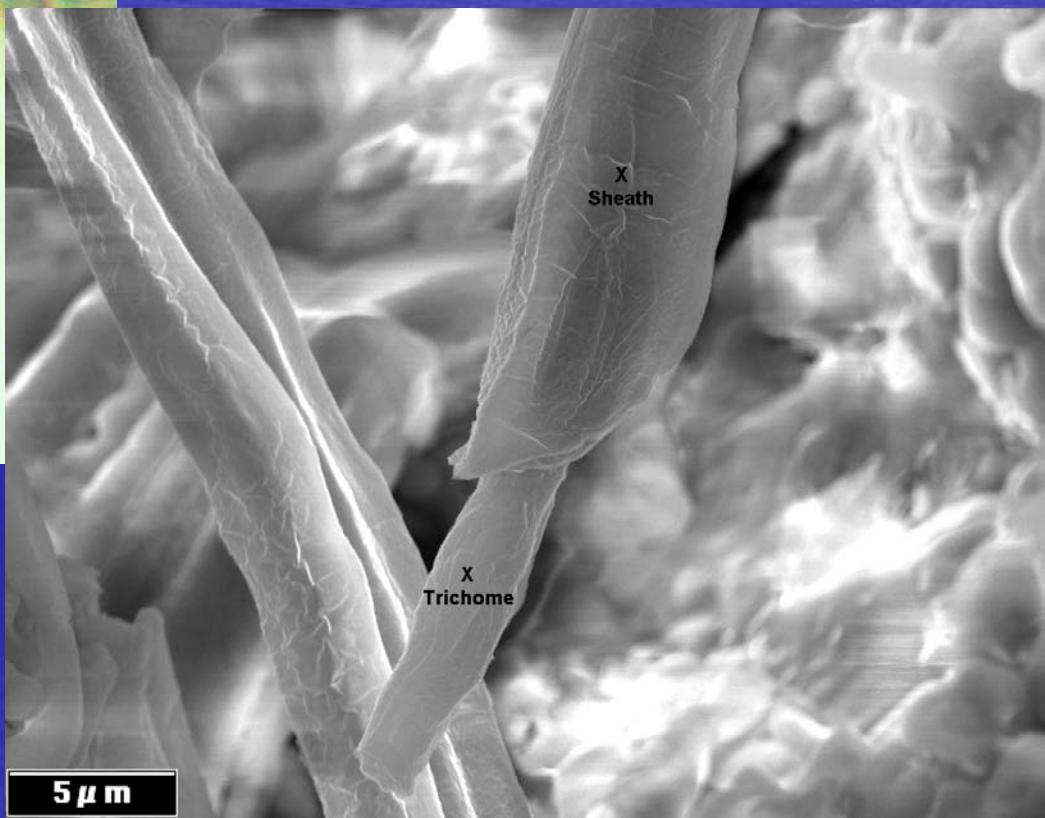


Morphotypes of Order *Oscillatoriales* in the Orgueil CI1 Meteorite



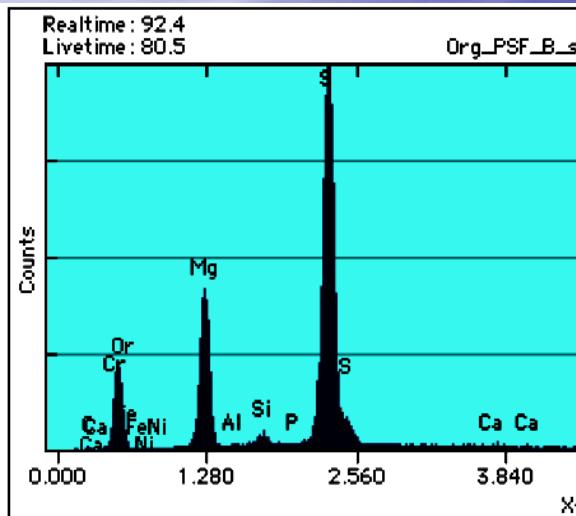
Lyngbya wollei filament with
emergent hormogonium &
Hollow Sheath

Orgueil Filament with
emergent hormogonium &
Hollow Flattened Sheath





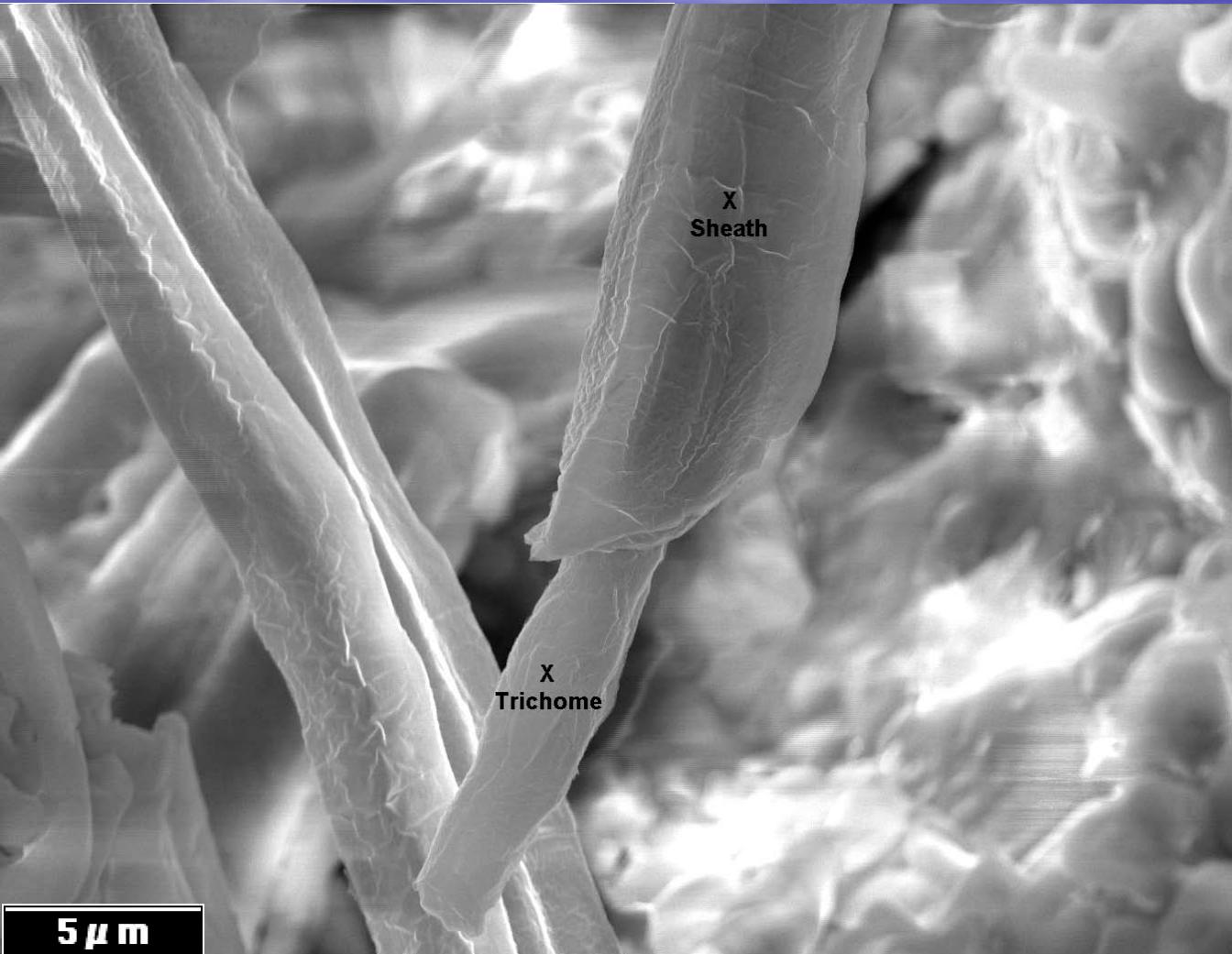
Morphotypes of Order *Oscillatoriales* in the Orgueil CI1 Meteorite



Quantitative Results for Org_B_h03b, sheath
Analysis : Bulk Method: Standardless
Acquired 14-Jul-2004, 15.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %
C	0.00	0.01	5.40	0.01
O	30.54	1.34	0.48	45.37
Mg	15.74	0.88	0.57	15.39
Al	0.00	0.00	1.92	0.00
Si	0.95	0.35	1.96	0.80
P	0.00	0.00	1.55	0.00
S	50.58	1.32	0.28	37.50
Ca	0.00	0.00	1.90	0.00
Cr	0.00	0.00	2.52	0.00
Fe	2.18	0.75	2.77	0.93
Ni	0.00	0.01	4.00	0.00
Total	100.00			

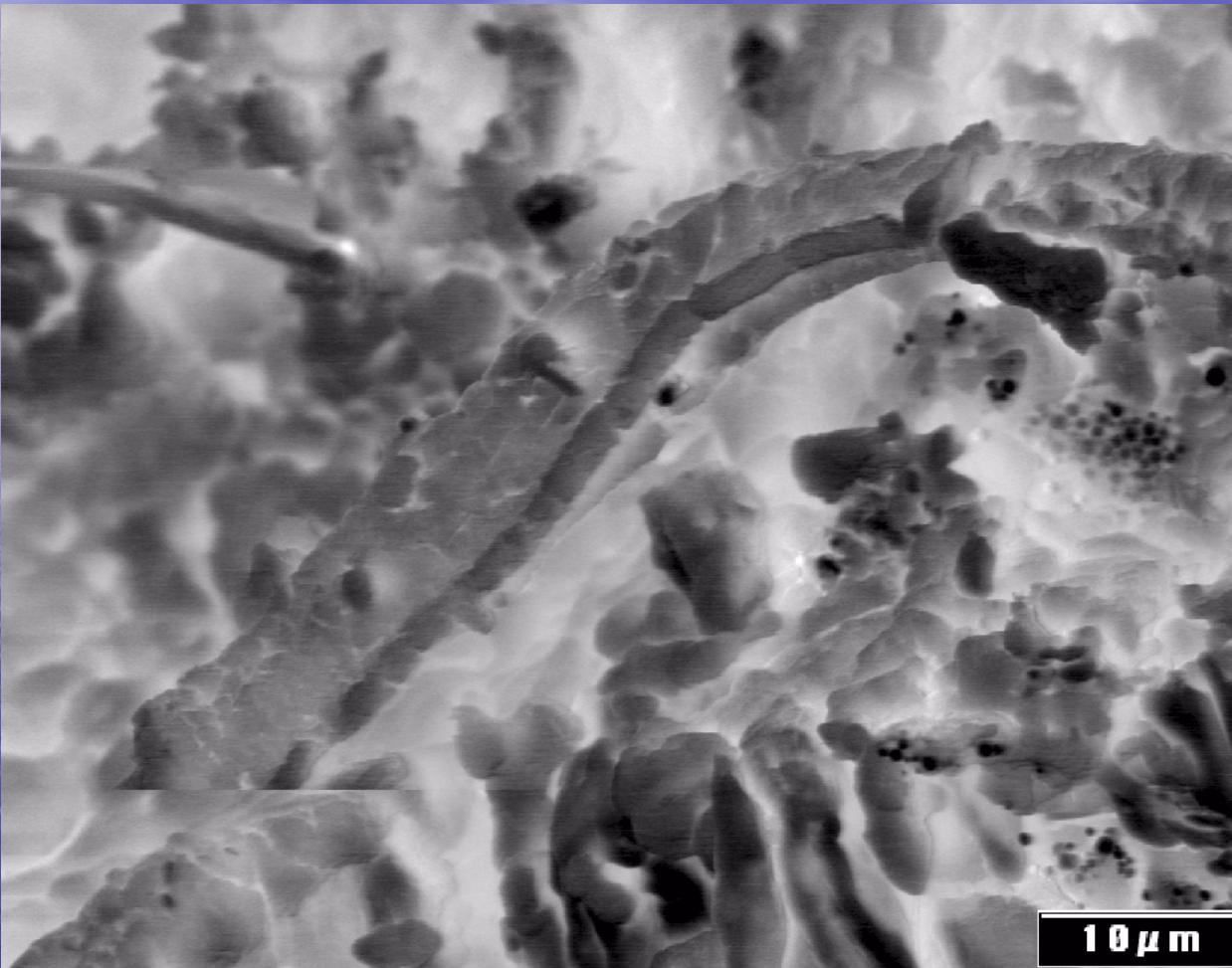
? These elements are statistically insignificant.



Sheath: Mg 15%; S 38%; O 45%; C < .1%; Fe 1%; O/C > 450



Cells in Thick Sheath of *Lyngbya* sp. Filament in Orgueil Meteorite



Internal Structures – Trichome with Cylindrical Cells ($2.5 \times 7.5 \mu$) in Thick Sheath (~*Lyngbya* sp.)



Morphotypes of Order *Oscillatoriales* in the Orgueil CI1 Meteorite



50 μ m



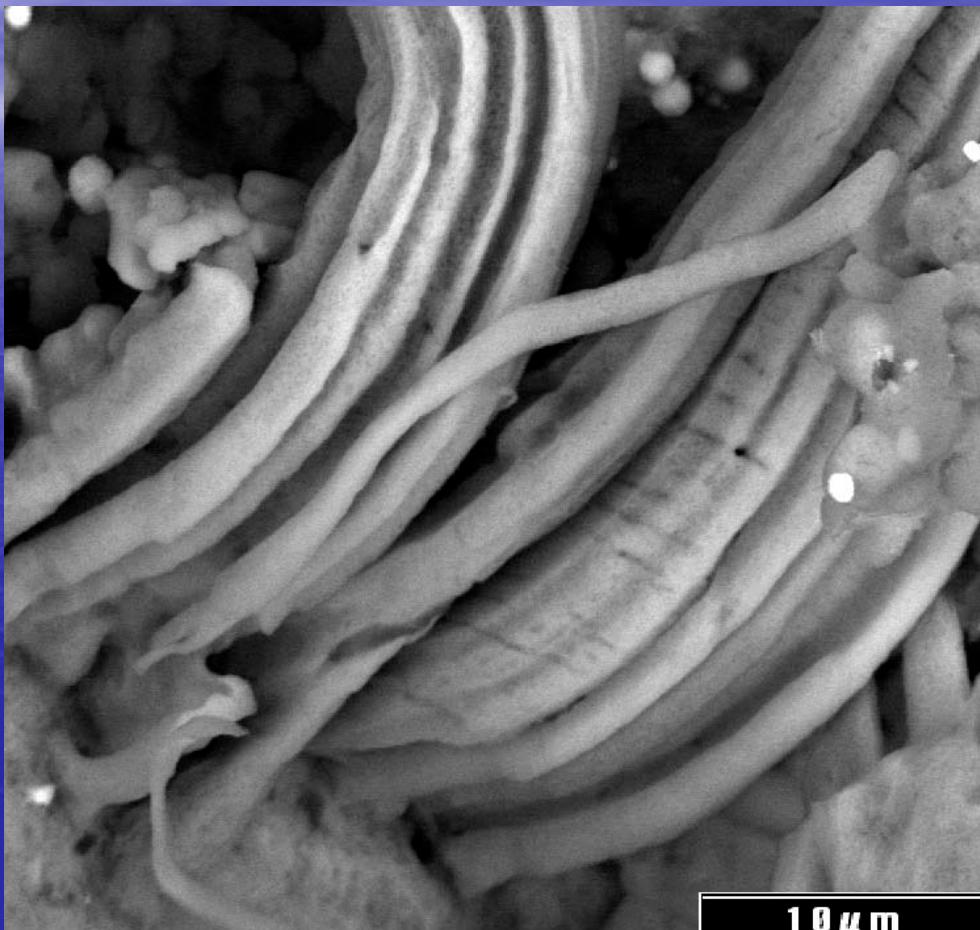
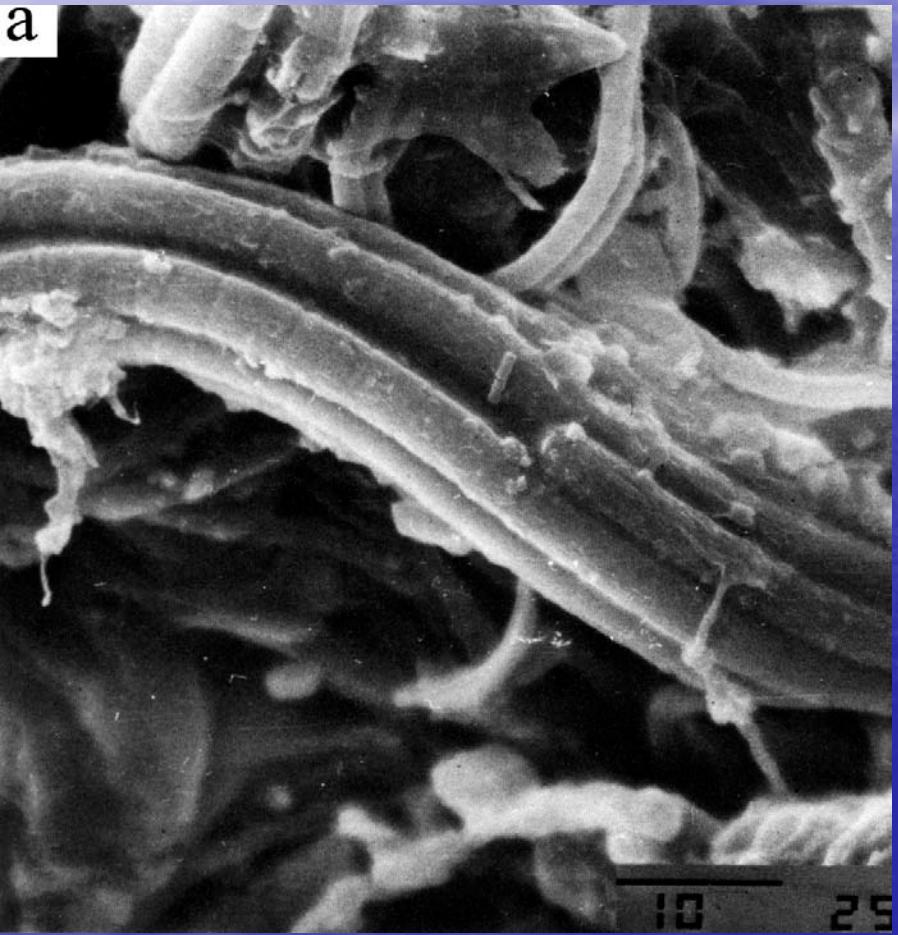
Spiral Filament (7 μ) of Uniseriate Trichomic (3 μ) Prokaryote
Morphotype of Cyanobacteria: *Lyngbya spiralis*



Morphotypes of *Oscillatoriales* in Orgueil & Living *Microcoleus*



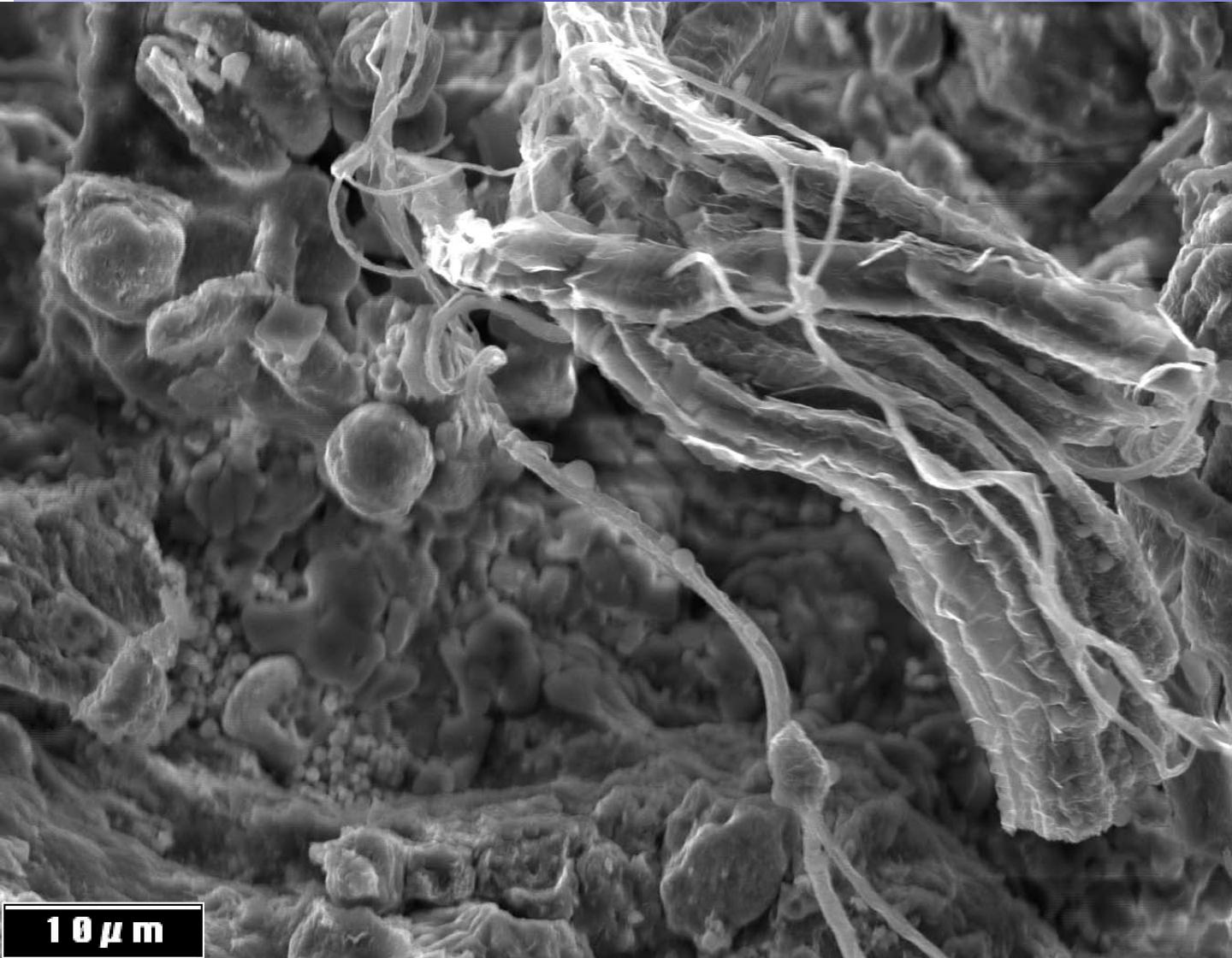
a



Trichomes in common sheath of (a.) living *Microcoleus chthonoplastes* compared with (b.) Mineralized remains in Orgueil



Morphotypes of *Oscillatoriales*: *Microcoleus* Mat in Orgueil

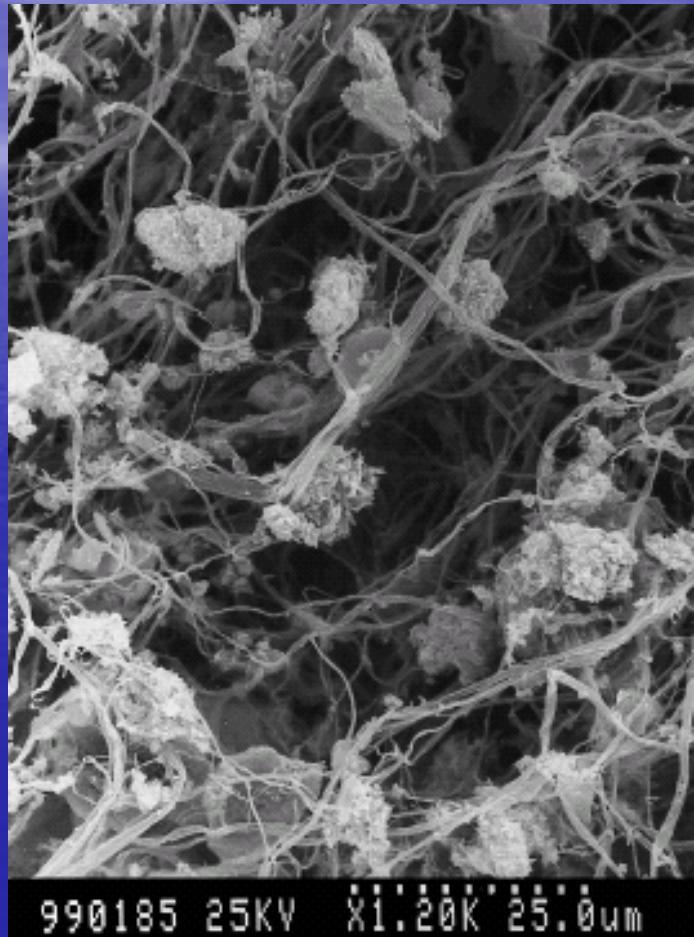
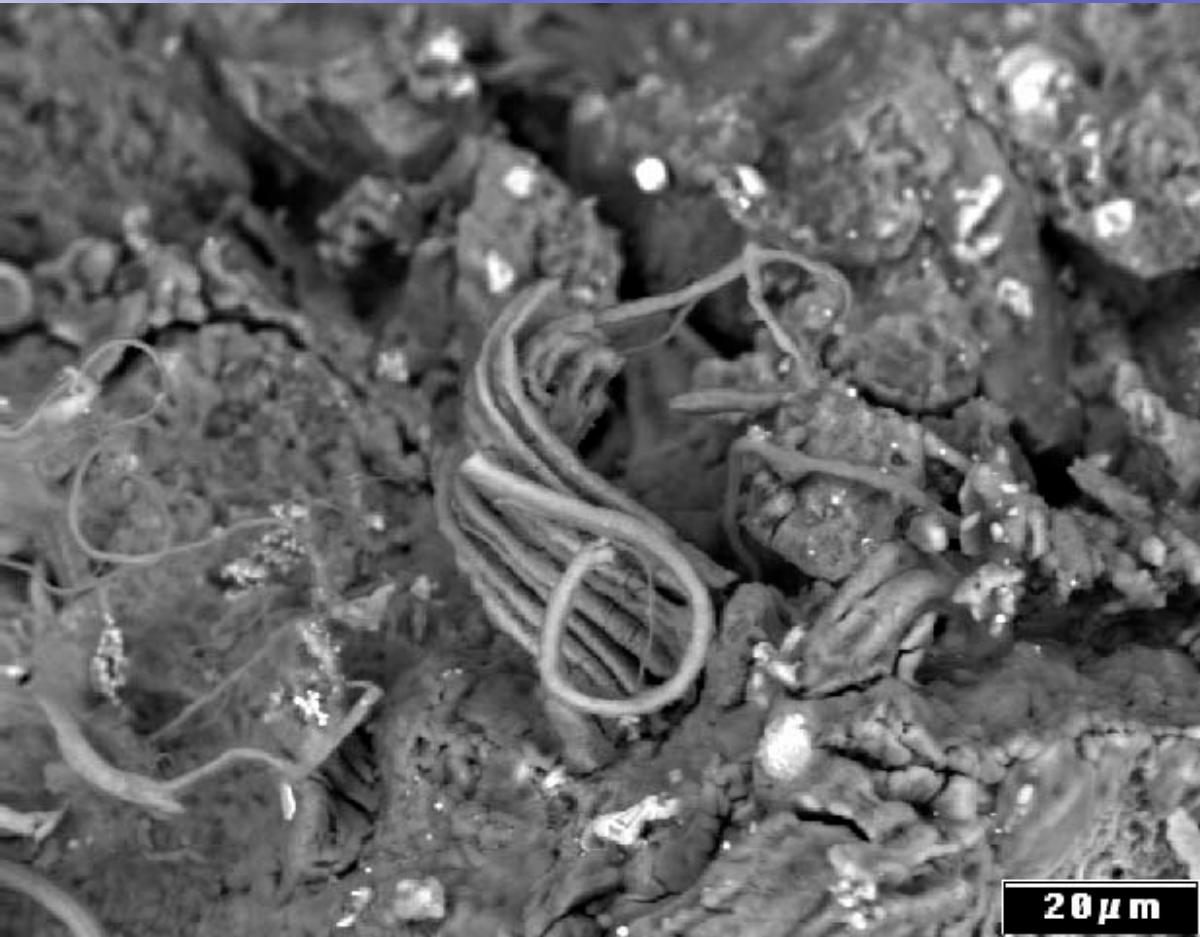


10 μm

Trichomic Cyanobacterial Mat in Orgueil



Morphotypes of *Oscillatoriales*: *Microcoleus/Phormidium* Mat in Orgueil



*Mats of Oscillatoriales:
Microcoleus/Phormidium in
Orgueil Meteorite and in
French Polynesia*

Microbialites in a modern lagoonal environment:
nature and distribution, Tikehau atoll (French Polynesia)
S. Sprachta^{a,*}, G. Camoin^{a,b}, S. Golubic^c, Th. Le Campion^d



Morphotypes of *Oscillatoriales*: *Spirulina* Mat in Orgueil



Morphotypes of Trichomic *Spirulina* spp.



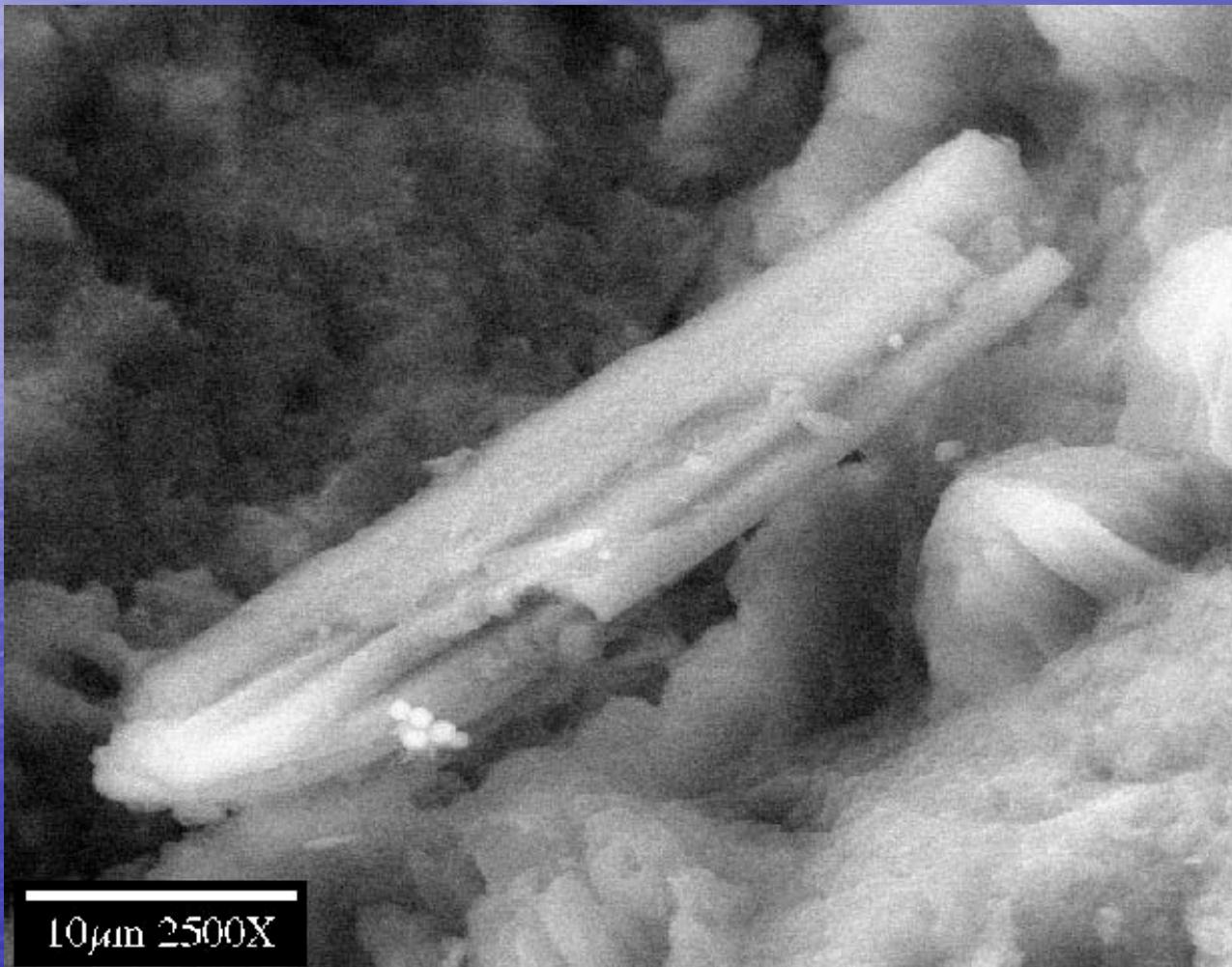
Morphotypes of *Oscillatoriales*: *Oscillatoria* Mat in Orgueil



Morphotypes in Orgueil of Filaments ~ *Phormidium* sp.
(Trichomes uniseriate: Cells ~ 1 μ Wide X 1.5-2 μ long)



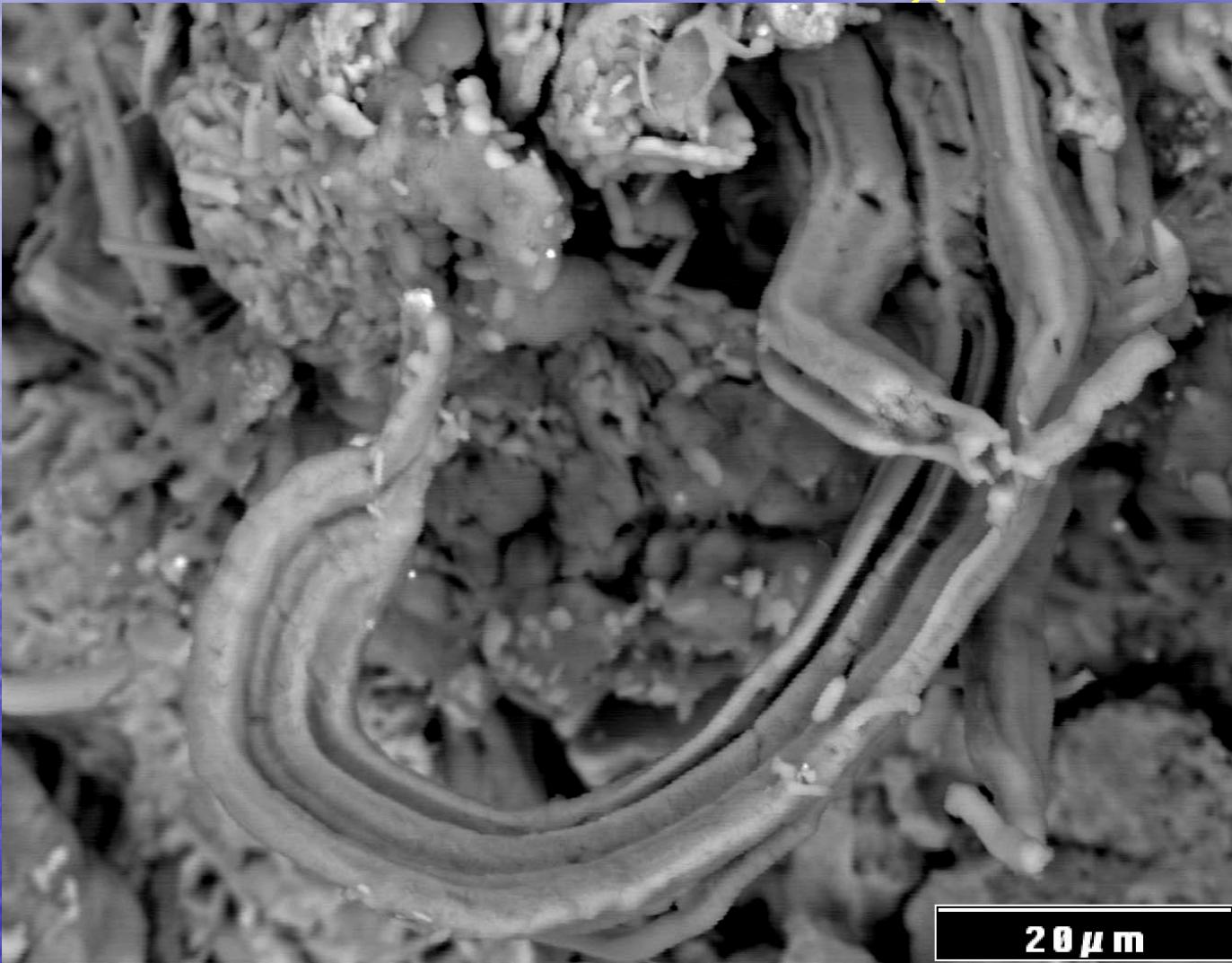
Morphotypes of *Oscillatoriales*: *Microcoleus* Filaments in Orgueil



Embedded Filaments with Multiseriate Trichomes in Orgueil
Morphotypes of *Microcoleus chtonoplastes*



Morphotypes of *Oscillatoriales*: *Phormidium* Mat in Orgueil



Filaments with Emergent Hormogonia ~ *Phormidium* sp.;
O 42%; S 30%; Mg 14%; Fe 6%; C 5.4%



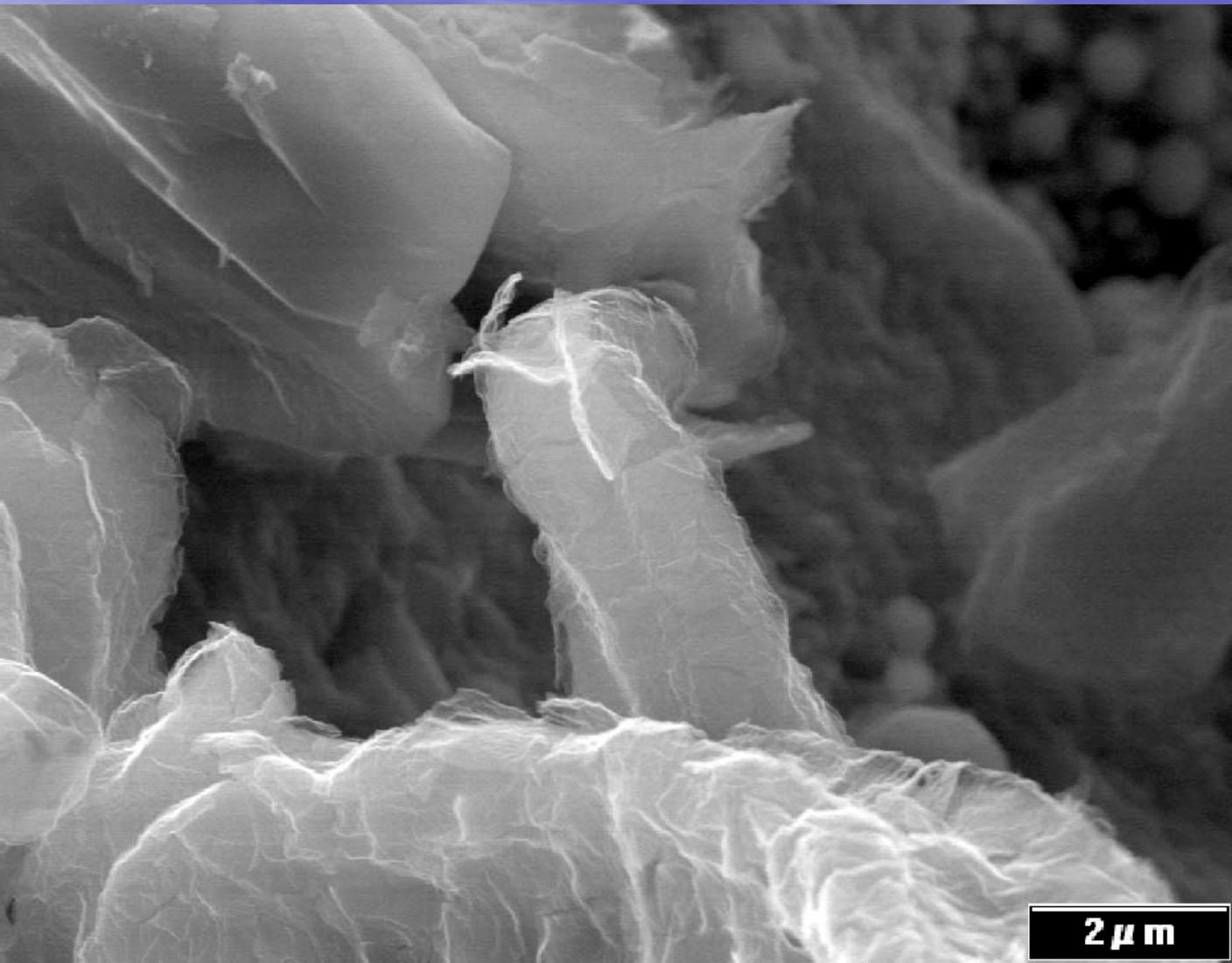
Morphotypes of *Oscillatoriales*: *Phormidium* sp. in Orgueil



Attached Terminal End (Diameter 3 μ) of 1.8 μ Hollow & Flattened Carbonized Sheath in Orgueil



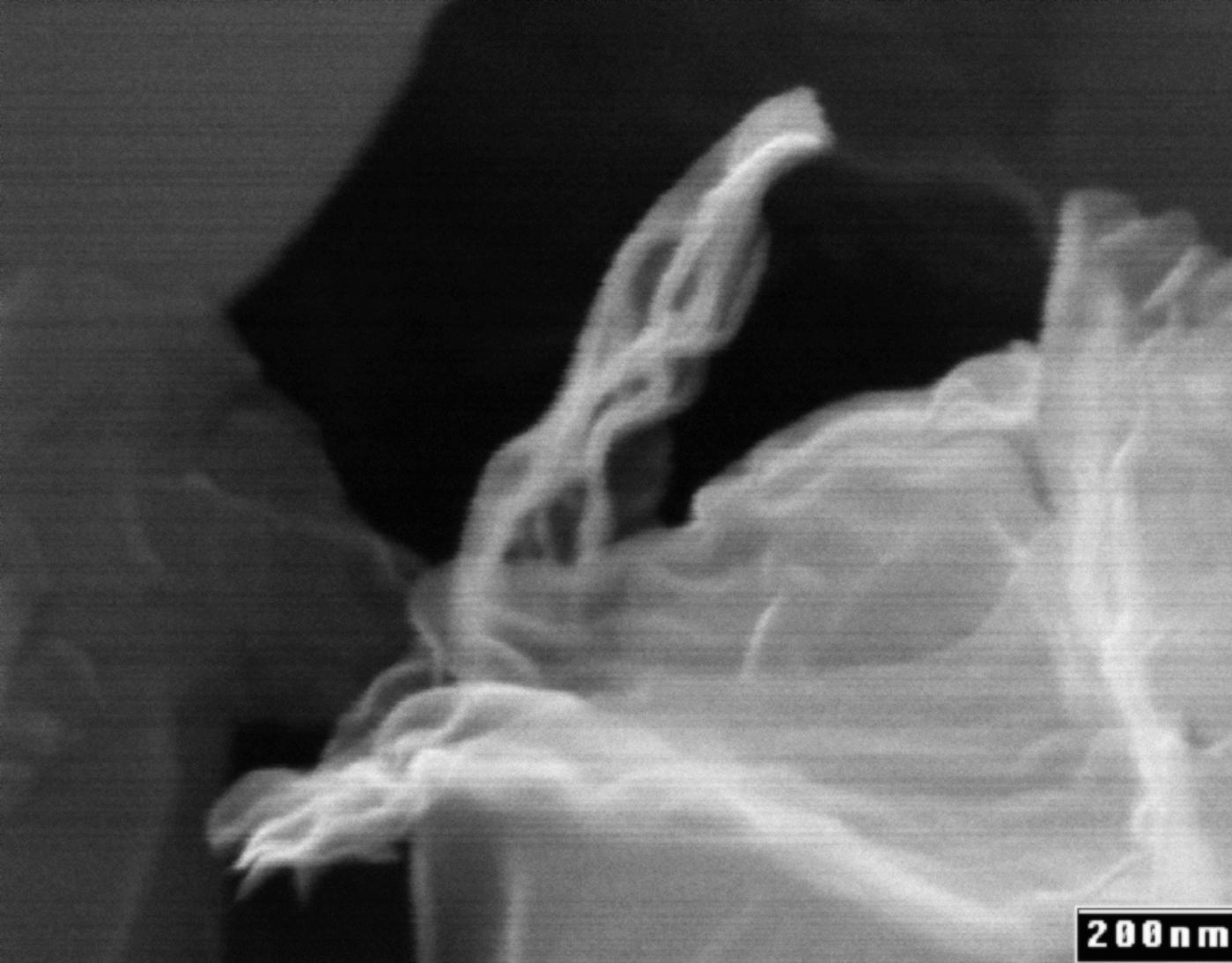
Nanostructures in Orgueil Filaments: Fimbriae



Filaments with Lophotrichous Tufts of Fimbriae



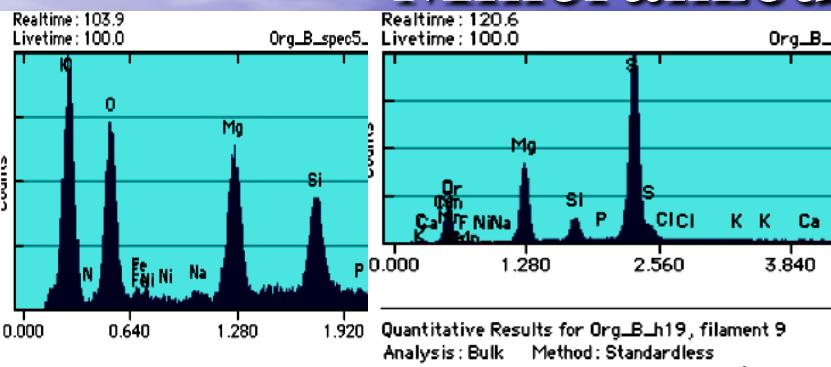
Nanostructures in Orgueil Filaments: Fimbriae



Lophotrichous Tuft of Fimbriae @ 80kX



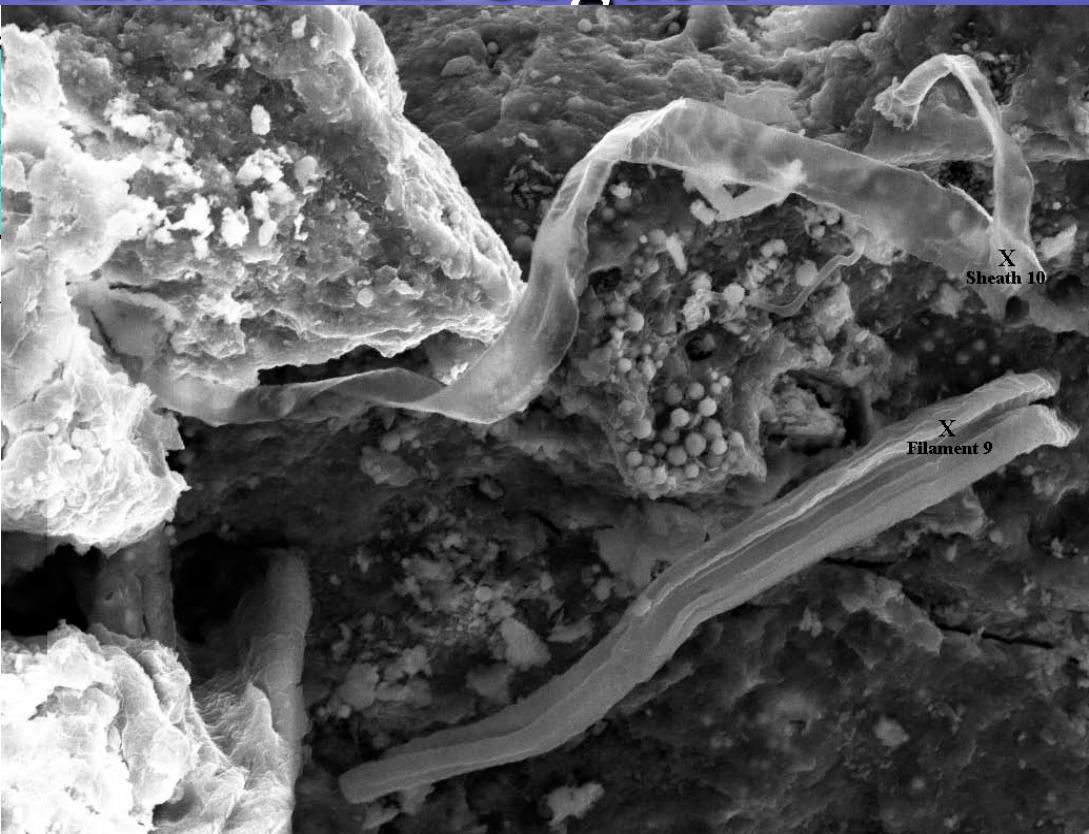
Carbonized Flattened/Twisted Sheath 10 μm Away From Mineralized Filament in Orgueil



Quantitative Results for Org_B_h19, loose sheath 1

Analysis: Bulk Method: Standardless
Acquired 21-Jul-2004, 5.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %
C	36.09	1.48	0.33	54.79
N ?	0.00	0.00	3.98	0.00
O	11.74	0.79	0.50	13.39
F ?	0.00	0.00	2.51	0.00
Na ?	0.74	0.29	4.20	0.58
Mg	8.16	1.04	1.14	6.12
Al ?	0.93	0.37	3.80	0.63
Si	9.51	0.85	1.33	6.17
P ?	1.02	0.41	5.24	0.60
S	30.23	1.44	1.11	17.20
Cl ?	0.00	0.01	4.34	0.00
K ?	0.01	0.02	6.99	0.00
Fe ?	1.56	0.57	4.03	0.51
Ni ?	0.00	0.00	2.82	0.00
Total	100.00			Total 100.00



Atomic% - Flattened Sheath 10

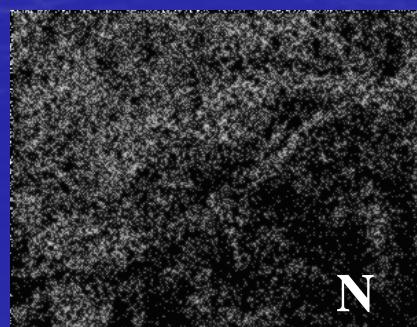
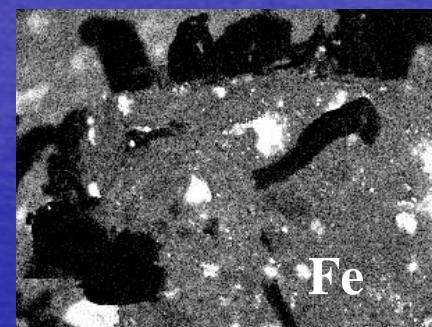
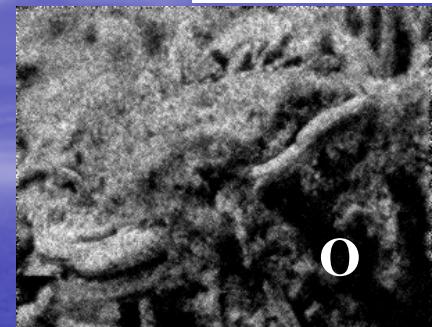
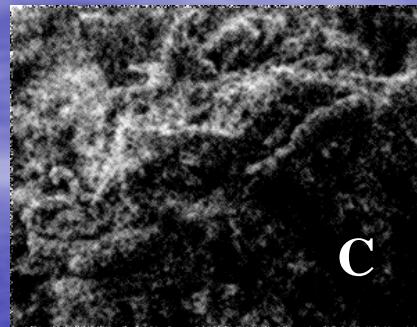
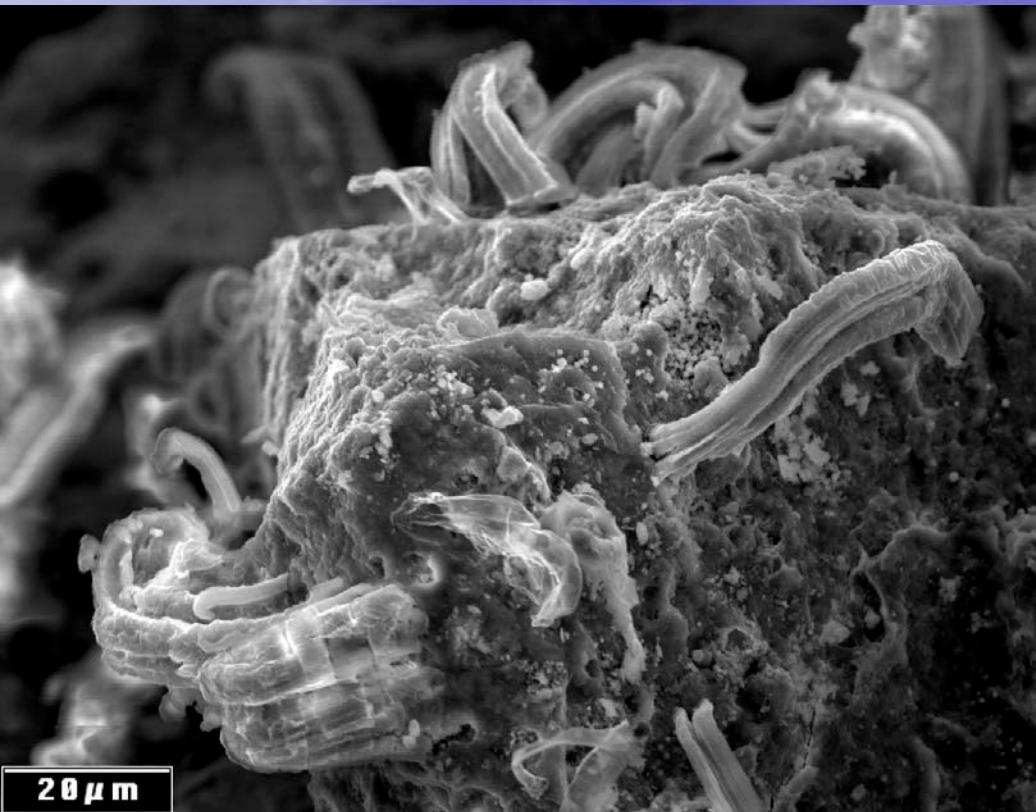
C 54.8%; S 17.2; O 13.4; Mg 6.1; Si 6.2; Fe 0.5; N 0% - O/C 0.24

Atomic% - Filament 9

C 8.9%; S 33.8%; O 35.1; Mg 14.2; Si 4.0; Fe 3.1; N 0% - O/C 3.9



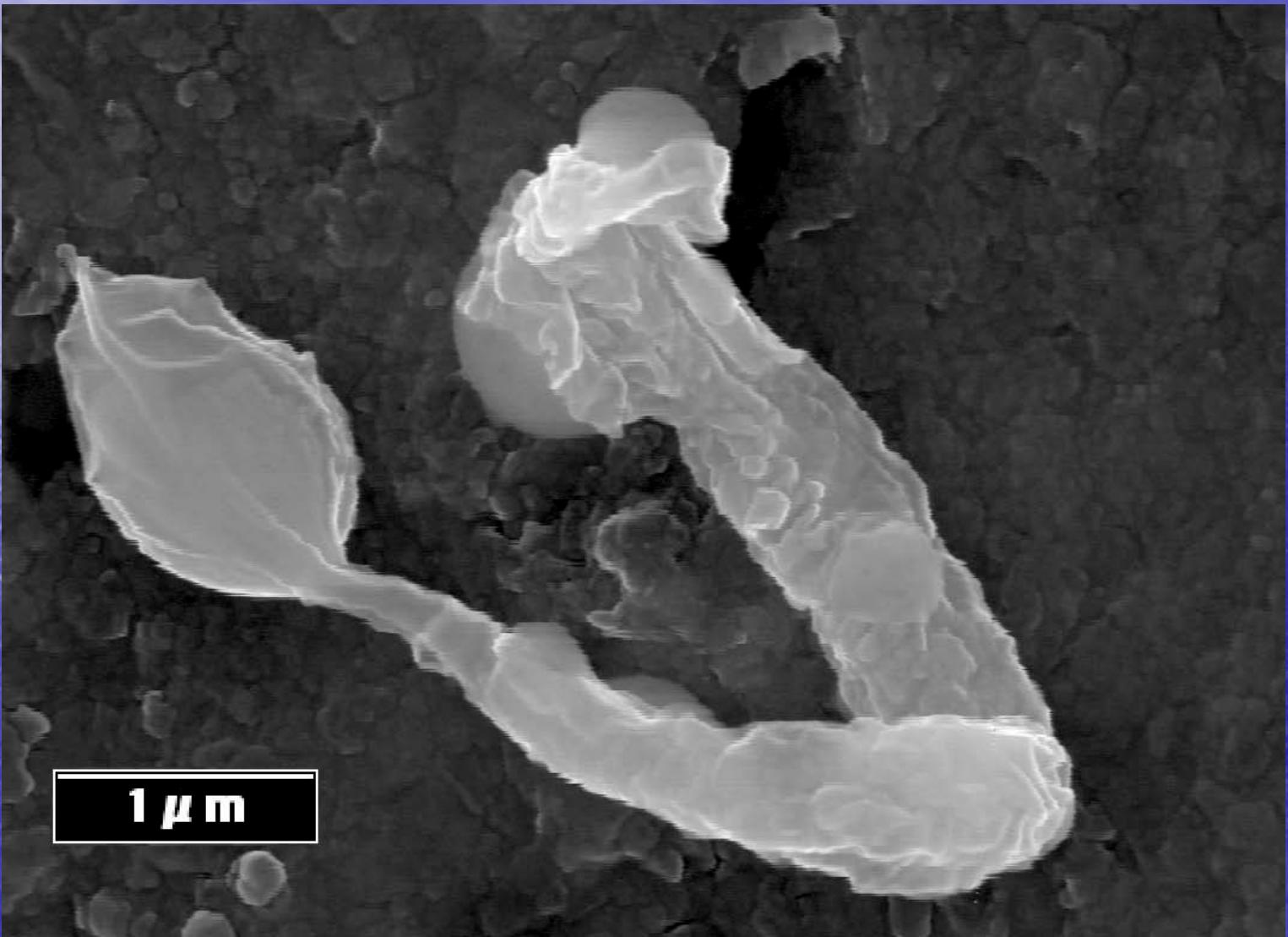
Indigenous Microfossils in Orgueil



Filaments and Sheaths Embedded in Orgueil Rock Matrix with
2D X-Ray Maps for Carbon, Oxygen, Silicon, Iron, Nitrogen & Sulfur

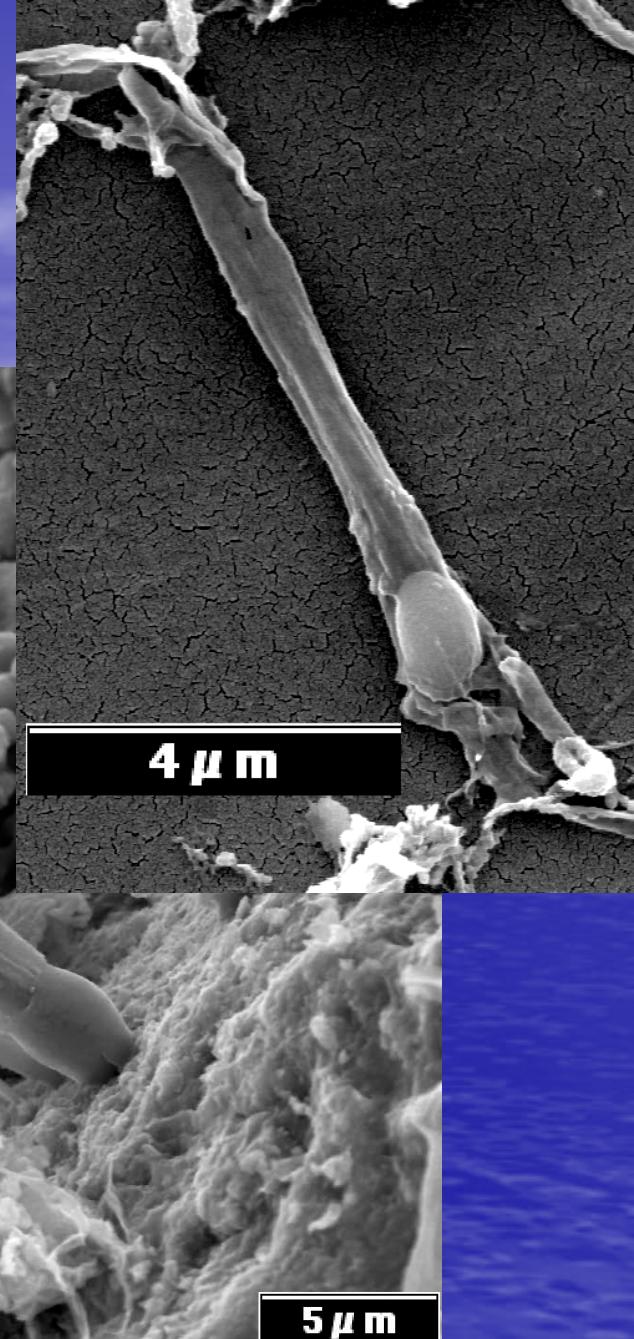
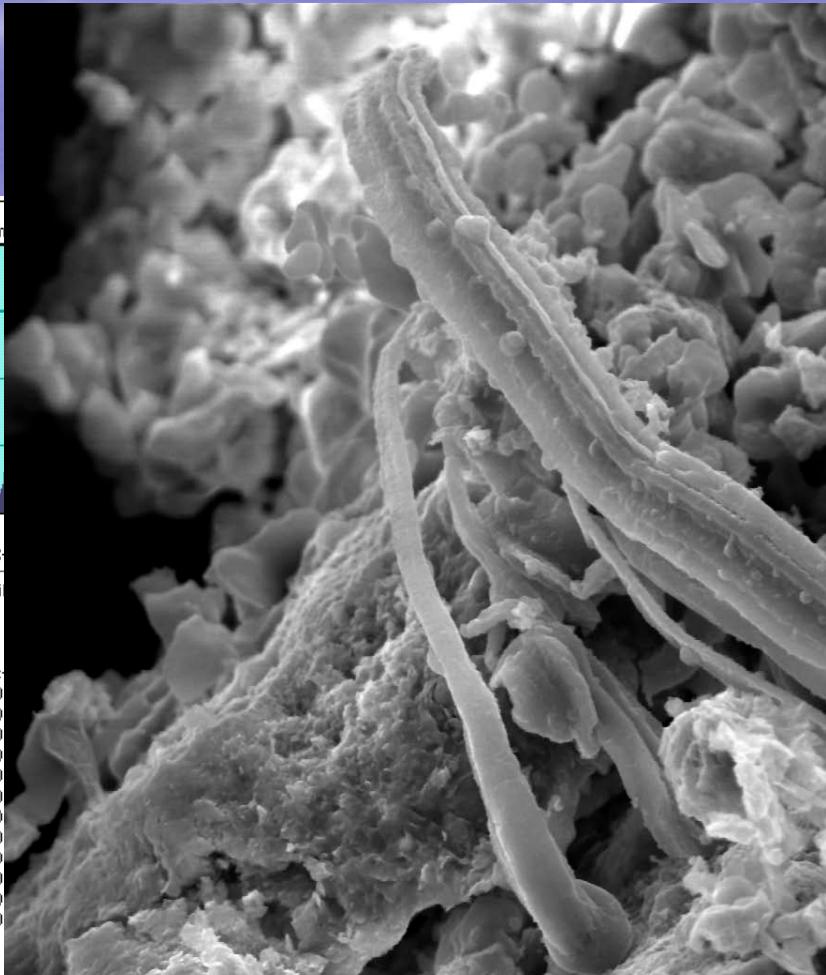
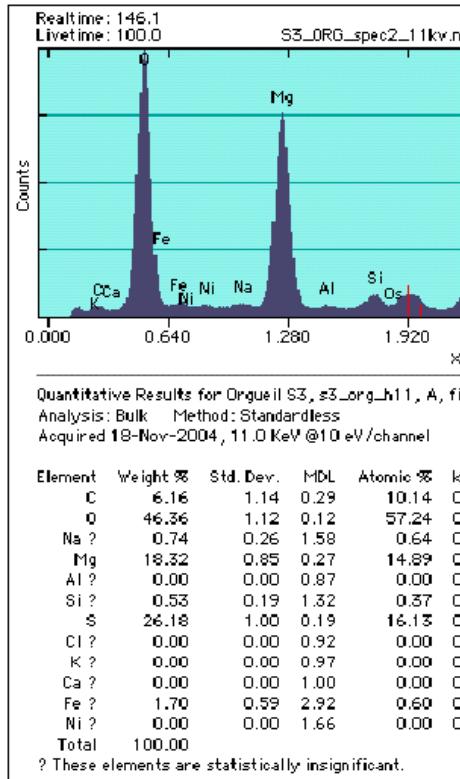


Morphotypes of Order *Nostocales* in Orgueil CI1 Meteorite : *Rivularia* ~ *Cylindrospermum* sp.





Morphotypes of Order *Nostocales* in Orgueil ~ *Calothrix* sp



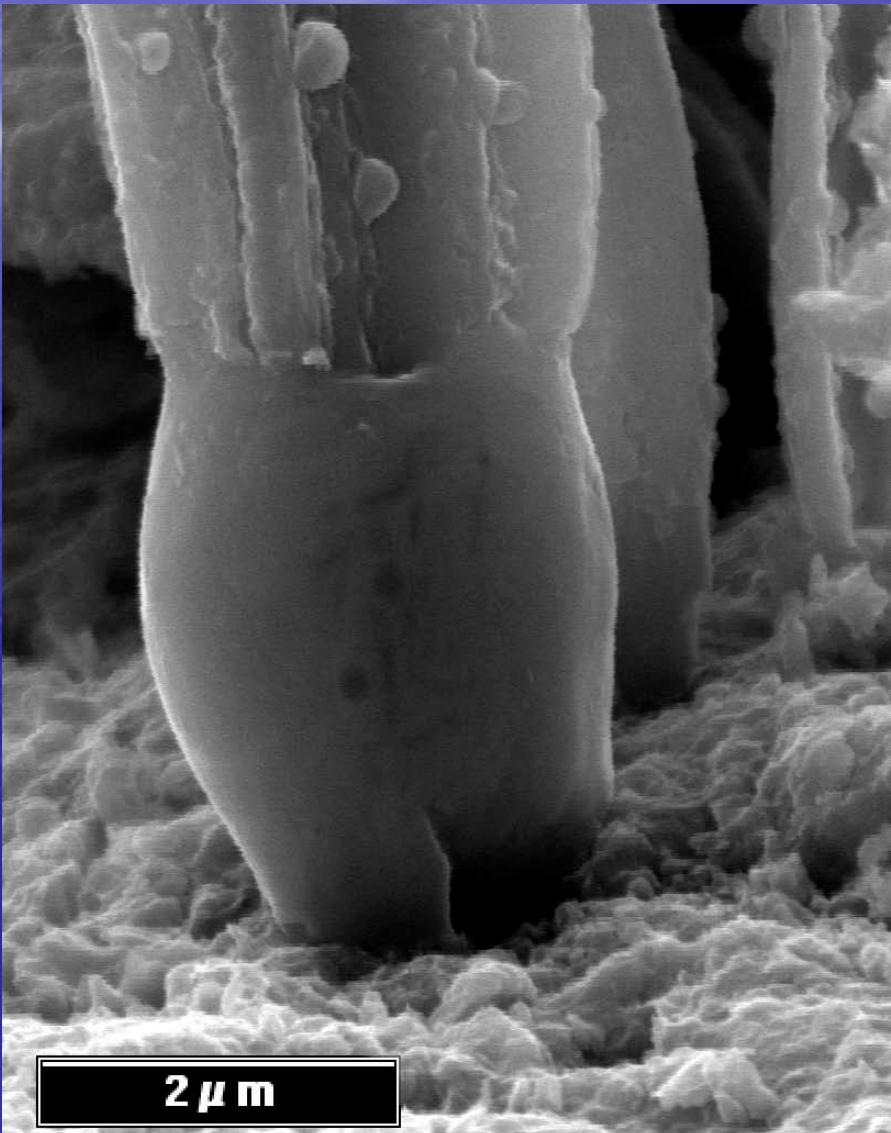
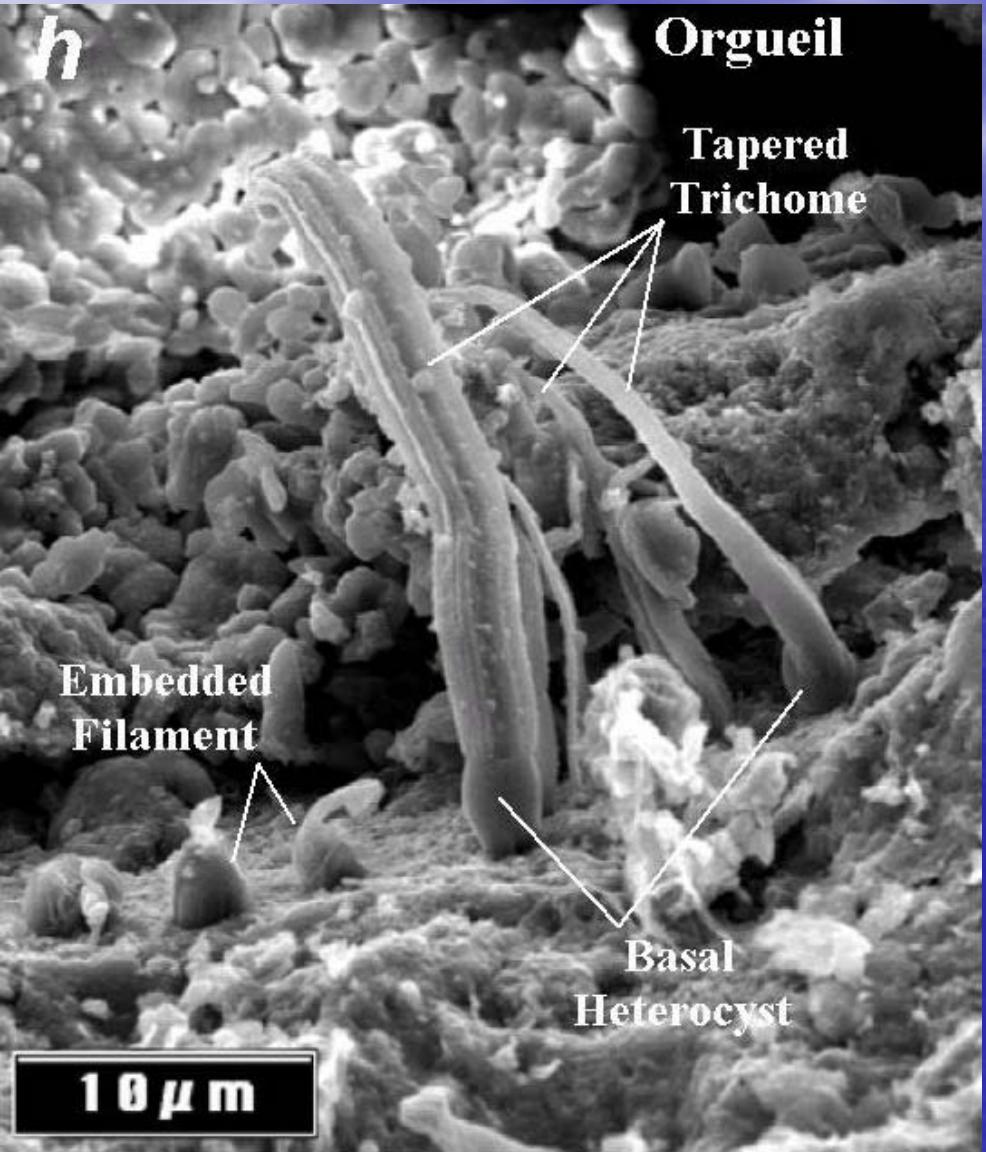
Living *Calothrix* & Heterocystous Filament in Orgueil



Morphotypes of Order *Nostocales* in Orgueil ~ *Calothrix* sp.

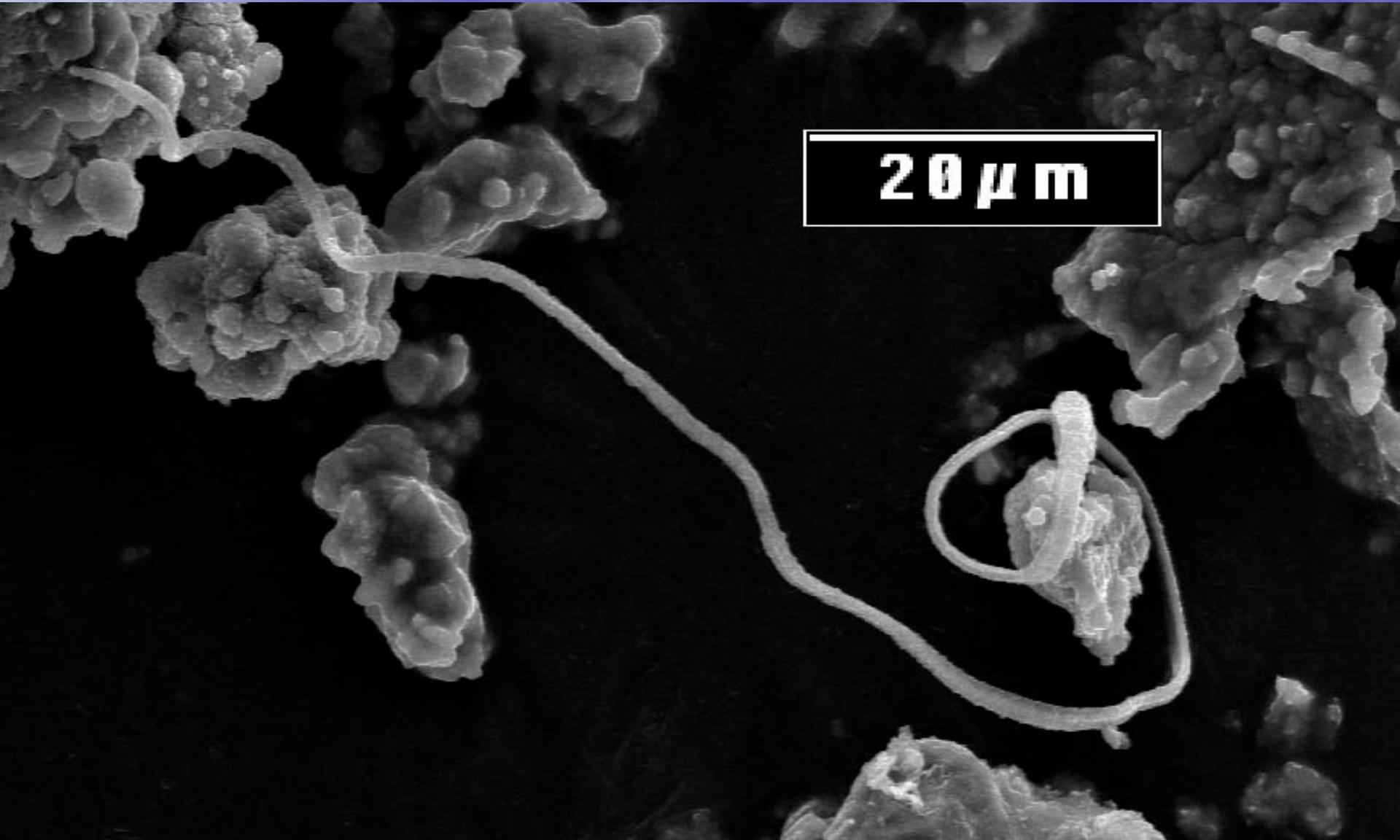


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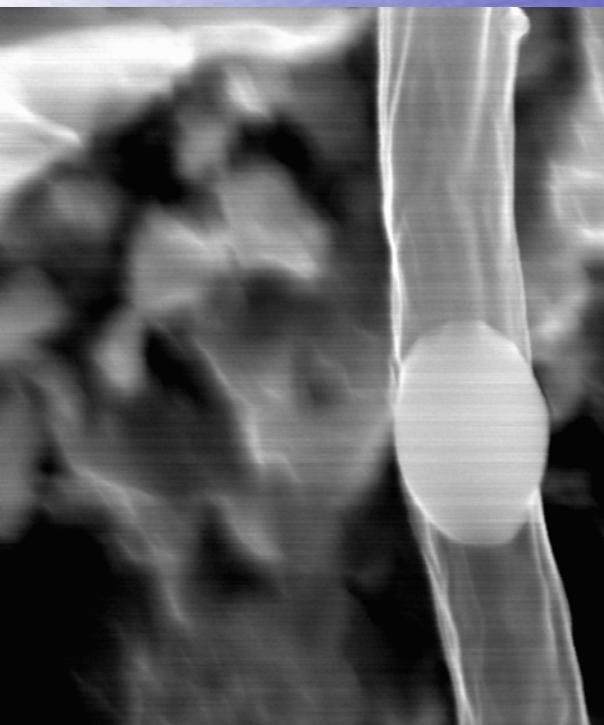


Rivularian Morphotypes in Orgueil *Cylindrospermum* sp.





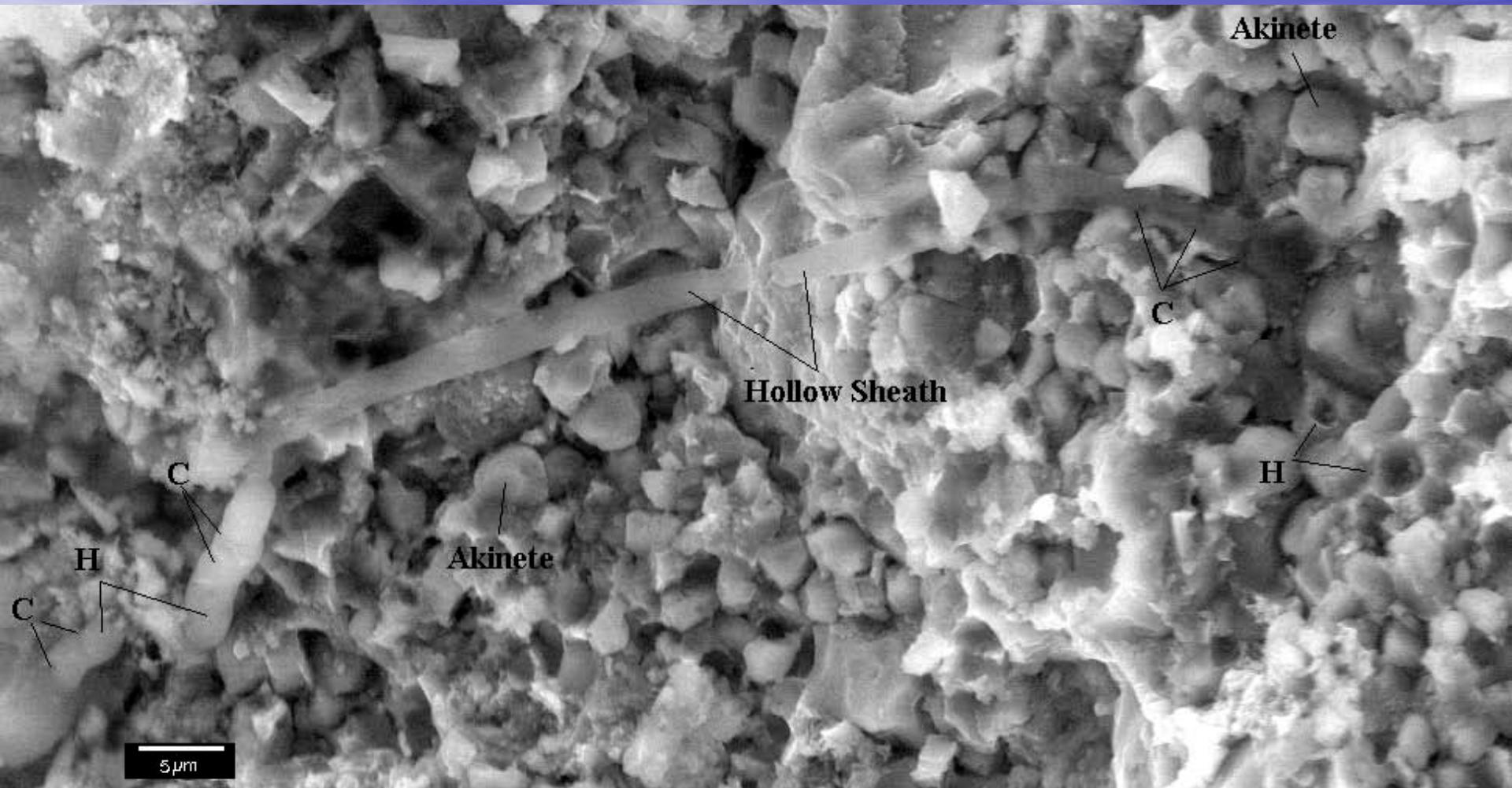
Morphotypes of Order *Nostocales* in Orgueil with Intercalary Heterocyst ~ *Nostoc* sp.



Hollow Sheath with Single Internal (0.8x1.4 micron) Cell



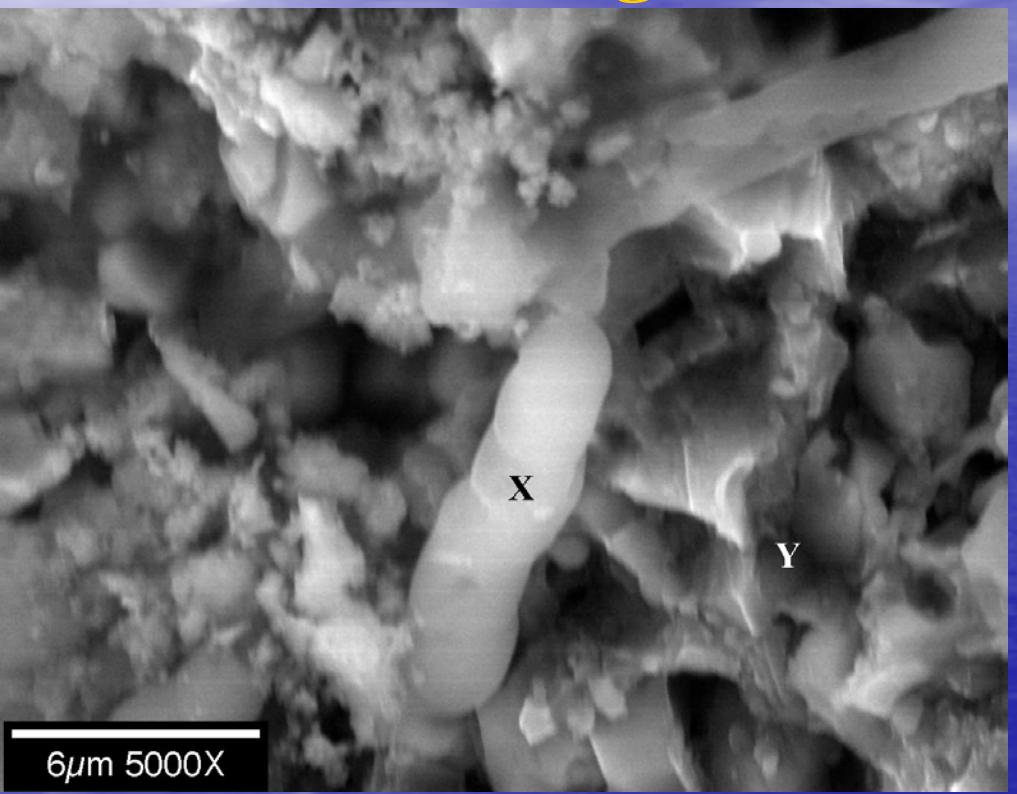
Morphotypes of Order *Nostocales* in Murchison with Hormogonium



Embedded Hollow Sheath, Emergent Trichomes & Coiling Hormogonia (H), Cross-Wall Constrictions (C), and Akinetes



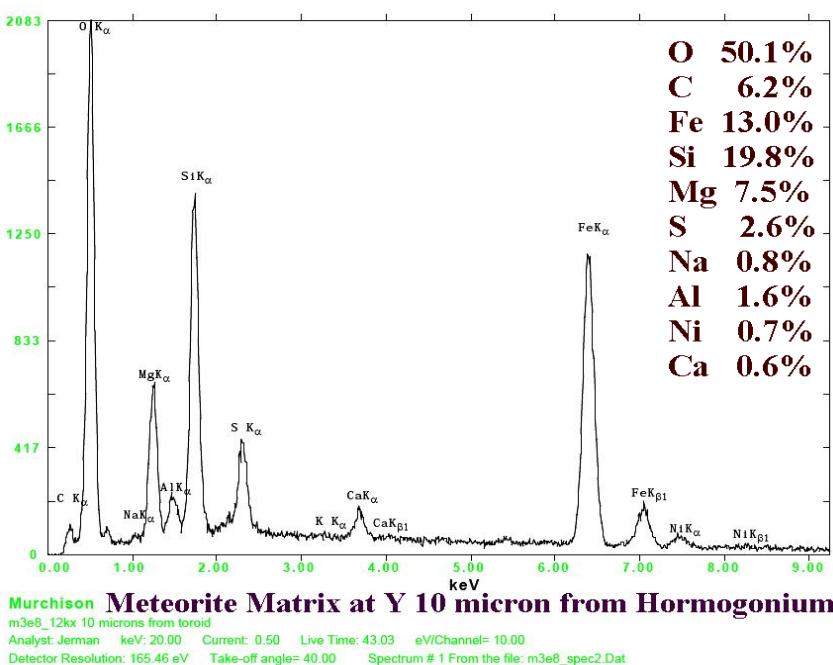
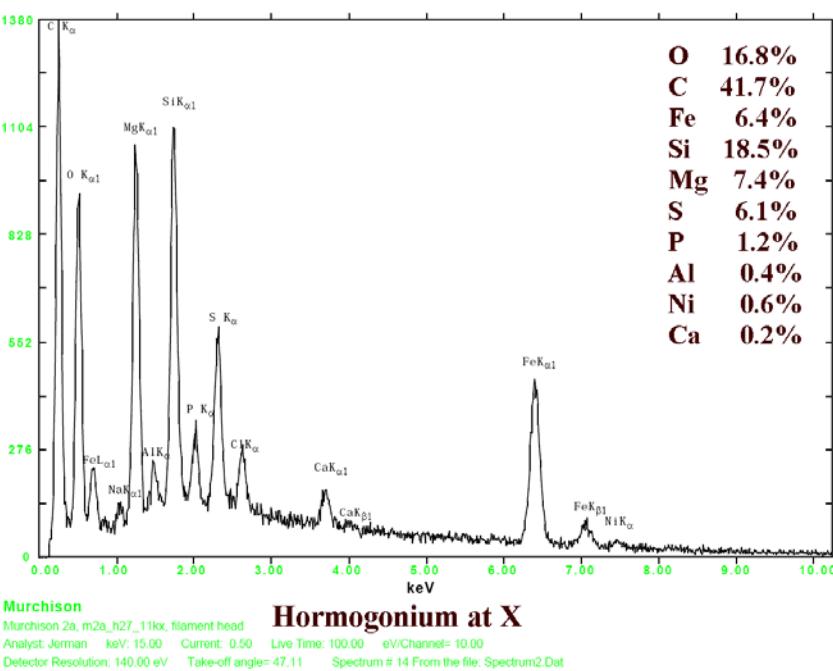
Carbon Enrichment & Nitrogen Loss



Constrictions in Emergent Trichome & Flattened Sheath Indicate Spherical or Cylindrical Cells ~ 2 μ Diameter

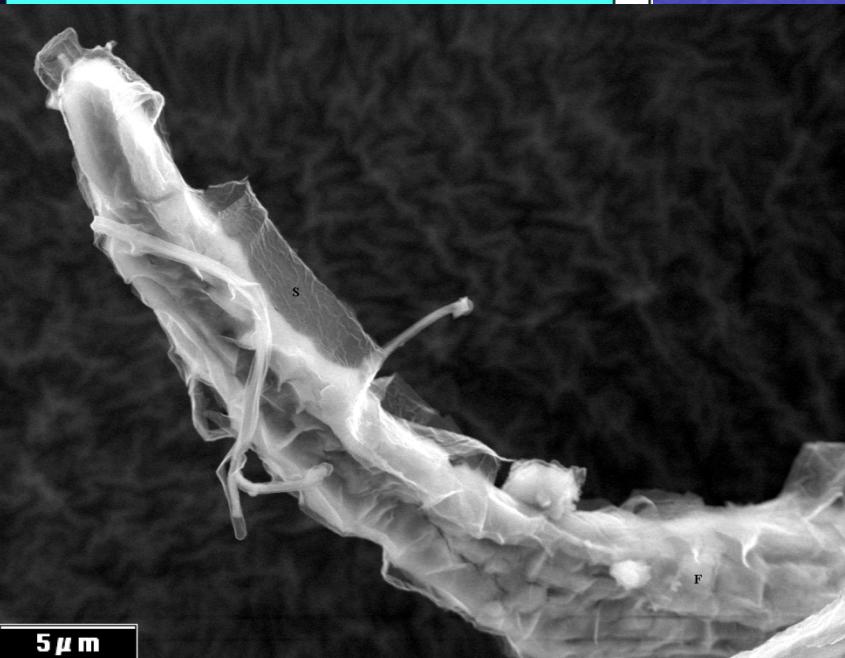
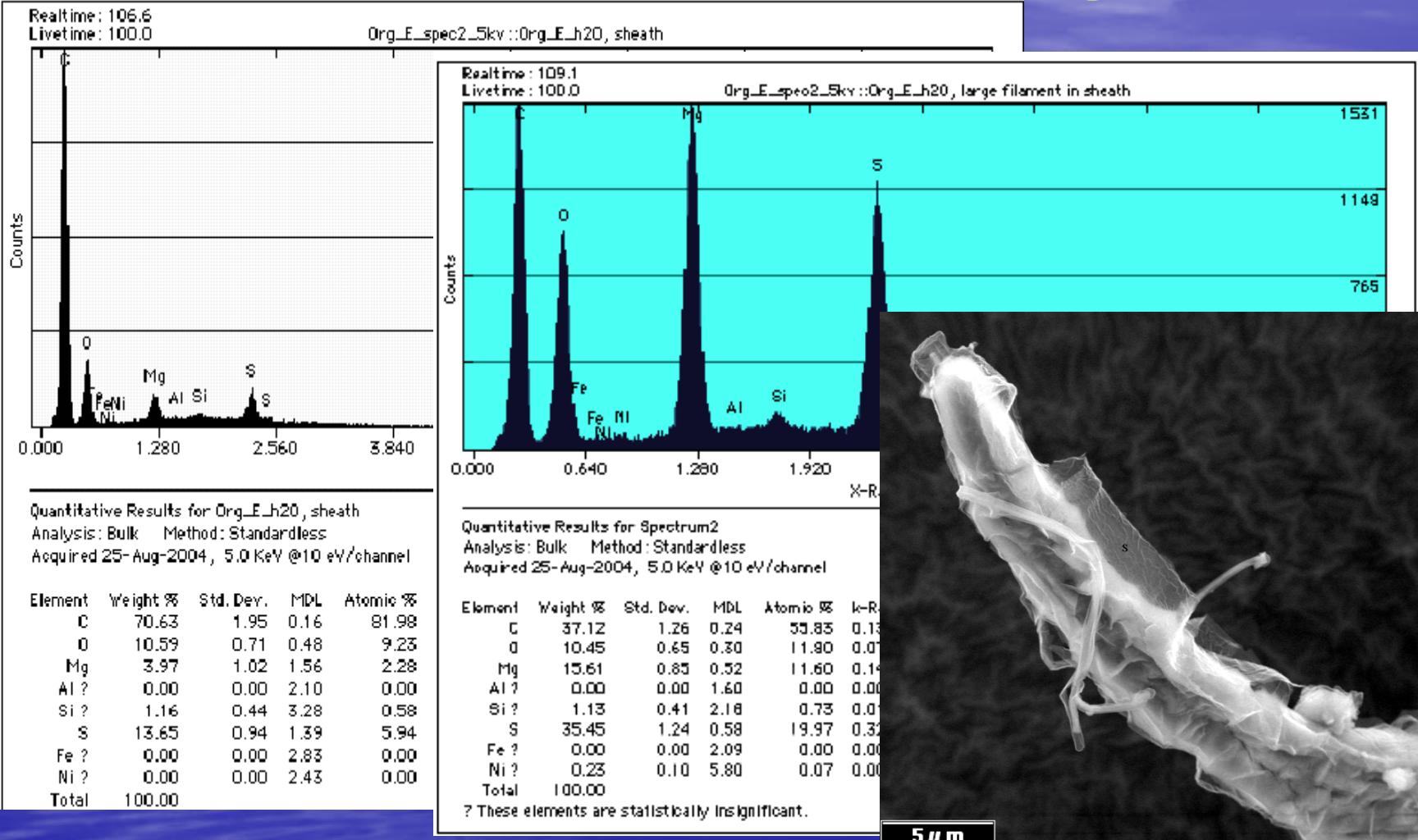
Hormogonium: C/N>83; O/C=0.3

Meteorite Matrix: C/N>12; O/C=8.0





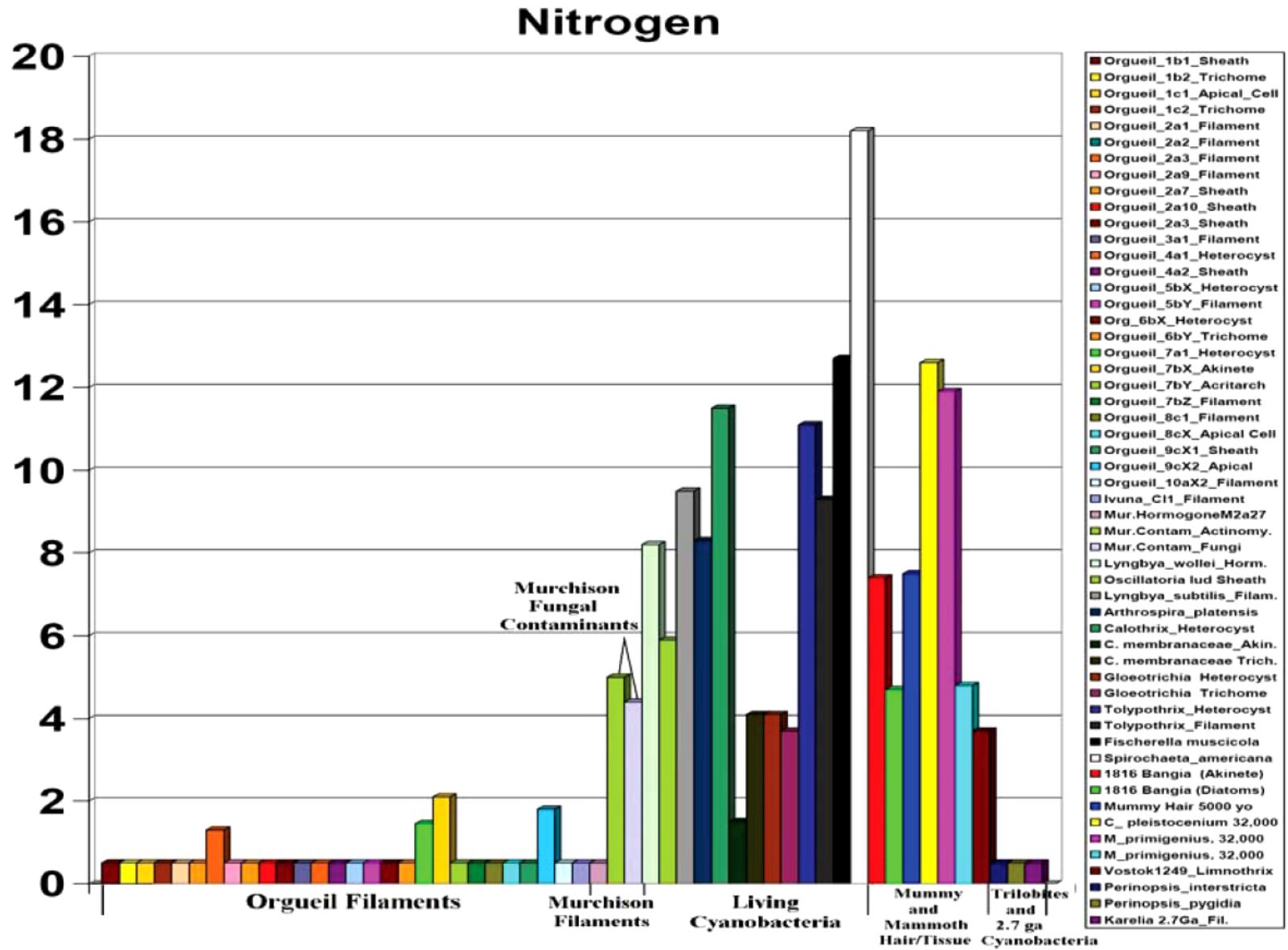
Morphotypes of Order *Stigonometales* in Orgueil

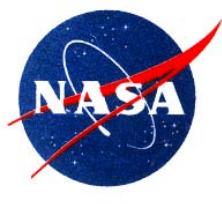


Epsomite infilled Cyanobacterial Filament (O/C=0.2) with Emergent Trichomes and Kerogenous Sheath (N< 0.3%; O/C=0.1)



Nitrogen in Meteorite Filaments, Modern Cyanobacteria & Ancient Biological Remains





Biomarkers in Orgueil and Murchison Meteorites



Purines & Pyrimidines: Stoks & Schwartz, *Nature*, **282**, 709, 1979

Chiral Amino Acids with Moderate to Strong L-Excess

Engel & Nagy, *Nature*, **296**, 837, 1982; Engel Andrus & Macko in *Perspectives in Astrobiology*, Klewer NY, 2005.

Only 8 of 20 Protein Amino Acids Present: (Glu, Asp, Pro, Gly, Leu, Sar, Ala, Val)

Missing Amino Acids

(Phe, Tyr, Lys, His, Arg & Trp) – Present in All Life Forms

But Absent in Hadrosaur Fossils & Never Detected in Murchison or Orgueil Carbonaceous Meteorites

Porphyrins, Phytane, Pristane & NorPristane

Kissin, *Geochm. Cosm. Acta*, **67**, 1723-1735, 2003

Pristane & Phytane - (2,6,10,14-tetramethylhexadecane) - C19 & C20 isoprenoid hydrocarbons derived from phytol chain of chlorophyll



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



Conclusions: Evidence of Indigenicity:

Orgueil Microfossils are found embedded in freshly fractured surfaces of meteorite matrix

- EDS Data Indicate forms are Carbonized or Mineralized Similar to Meteorite Matrix.
- Some forms are Devoid of Carbon and Others have Very High Carbon Content (~ Kerogen)
- Pollen Grains & Bio-Contaminants Not Detected
- Many Orgueil forms are Rare Species (Some of Entirely Unknown Biological Affinities)



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



Are the Meteorite Filaments Biogenic?

The Orgueil & Murchison Meteorites Contains a Large Suite of recognizable Cyanobacterial Filaments with Trichomes encased within External Sheaths

All 5 Orders of Cyanobacteria were Found Embedded in Freshly Fractured Meteorite Surfaces

- Filaments, Trichomes & Sheaths of Cyanobacteria with Cross-Wall Constrictions, Septae and Fimbriae
- Evidence of Motility: Twisted & Spiral Hollow Sheaths & Emergent Trichomes and Hormogonia
- Evidence of Mats, Colonies & Macrocolonies
- Evidence of Special Nitrogen Fixation Cells-Heterocysts



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



Evidence of Reproduction: Dividing cells, Diplococci, Chains of Cells, Akinetes, Cysts, Spores, Emergent Trichomes and Hormogonia

- Evidence of Ecologically Consistent Assemblages ~ Cryoconite Communities from Antarctica

Morphotypes of known species of *Microcoleus*, *Phormidium*, *Calothrix*, *Lyngbya* and *Spirolina* with associated *Hormogonia*, *Heterocysts* and *Fimbriae*

The Recognizable Cyanobacterial Filaments Found in the Orgueil and Murchison Meteorites are Undeniably Biological in Origin



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



Are the Meteorite Filaments Modern Bio-Contaminants?

The Orgueil & Murchison Filaments Typically Contain Nitrogen at Levels Below EDS Detectability (<0.5%)

Nitrogen is in All Amino Acids, Proteins, Enzymes, DNA and RNA Molecules in Living and Modern (<100,000 Yrs.) Organisms. Nitrogen Levels below 0.5% indicate Meteorite Filaments died long before Arrival on Earth.

Other Researchers have Detected only 8 of 20 Protein Amino Acids, 3 of 5 Nucleobases, no Ribose, Sugars or Chlorophyll in the Orgueil & Murchison Meteorites

Hence the Hypothesis of Bio-Contamination by Modern Cyanobacteria, Bacteria, Fungi, or Pollen is Rejected



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



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